CHANGING TECHNOLOGIES

A comparative study of eight processes
of transformation of technological regimes

PROEFSCHRIFT

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Voorwoord

Ik herinner me nog goed dat ik hoorde dat ik geslaagd was voor mijn middelbareschoolexamen. In de aula, temidden van overwegend vrolijke klasgenoten, onderging ik het bericht nogal gelaten. Natuurlijk was ik blij, maar ik dacht toch, enigszins teleurgesteld alsof ik meer verwacht had, 'Dit was het dus'. Nu mijn proefschrift klaar is heb ik een vergelijkbaar gevoel.
Natuurlijk heeft het afronden van mijn proefschrift heel wat meer zweetdruppels gekost dan het voltooien van mijn middelbare school. Heel wat meer dan toen ben ik aangelopen tegen mijn eigen intellectuele grenzen. Hoewel ik vrij onbezorgd begon aan mijn promotiewerk, heb ik de laatste anderhalf jaar ook regelmatig getwijfeld aan een goede afloop. Nog steeds word ik regelmatig overvallen door de angst dat het allemaal (nog) niet klopt, dat het (nog) niet af is.
Nu, achteraf, besef ik dat het beteuterde gevoel in de aula van mijn middelbare school voortkwam uit de wetenschap dat ik een leuke periode achter me liet, dat het 'voorbij' was. Ook nu weer sluit ik met enige weemoed een mooi tijdperk af, maar het wordt toch echt tijd dat ik mijn proefschrift uit handen geef.

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1

Introduction

In our modern industrial society, technology is seen as a motor of change. It is welcomed as bringing progress, but also feared as disrupting existing social order and introducing unintended side-effects. In both cases, it is the novelty introduced by technology which captures the imagination. But this is only half of the story.

> *The perpetual rush to novelty that characterizes the modern marketplace, with its escalating promise of technological transcendence, is matched by the persistence of preformed patterns of life which promises merely more of the same. Each major scientific advance, while appearing to presage an entirely new society, attests rather to the vigor and resilience of the old order that produced it. Every new, seemingly bold departure ends by following an already familiar path (Noble, 1977, xvii).*

While Noble exaggerates continuity in order to make his polemical point, he does address an important issue: the combination of continuity and change that makes up technological development. Seemingly radical technical changes are absorbed by the existing order, and may thus reproduce rather than transform it. As sociologists and economists of technology have demonstrated, technological change is cumulative and patterned[1], and its patterning derives from technical as well as social determinants. This is not to say that there is nothing new, only to emphasize the aspect of continuity in technological development, perhaps even inertia. Continuity, in the form of inertia, that is resistance to attempts to influence the course of technological development, becomes a problem when the effects of development and societal embedding of technology are criticized.

> *After decades of inaction, the Nation has begun to establish a more rigorous framework for responsibility for reducing highway casualties. Fundamental to the emergence of this national policy on motor vehicle safety is the recognition of a value and a capability. The value was the right of individuals not to have their physical integrity violated by hazardous vehicles - whether by product design or construction. The capability is an engineering one - the capability to invent the technological future once we decide that we want the benefits of such a future.*
>
> *The coupling of deeply felt values with graspable remedies represents a very dynamic impulse to reform. Yet, why did auto safety reform occur so late - in 1966 - and not two or three decades ago? Why have there been so few programs - and so late - to counteract other environmental and consumer hazards developed by the hand of men? Why do we continue to wait for disasters or near disasters before some action commences? Why have the "bodily rights" of people against the incursions of old and new technology been so inadequately articulated and protected? (Nader, 1983 (1967), 277).*

Nader's moral indignation is justified, but it hardly leads to an adequate diagnosis of what is happening and how one could do better. Critics like Nader tend to look for scapegoats: government officials, firms, or 'bad' technologies which are the causes

of what is wrong. If these causes are corrected, everything will be right.
Society as well as technological development are more complex than that such a linear diagnosis-cum-remedy can be the answer (even if Nader has successfully brought about changes in particular cases). In recent technology studies, there has been a tendency to fight so-called technological determinism, because it reduces the complexity of technological and social developments.[2] While Nader and most technology scholars are on the same side of the political fence: concern about the problems of technological society, their strategies are different: reducing complexity to enable political action, versus embracing complexity as an academic detour or to enhance the reflexivity of actors in the hope that they will do better.
I share the concerns of Nader and other critics of technology in modern society, and am as impressed by the complexities of technological development as any other technology scholar. But I am also intrigued by the patterns in technological developments, how these come about, and how they may be modified. In other words, I am interested in understanding the inertia, before condemning it (or praising it, as others might do, as the basis of progress). Not to reintroduce technological determinism, full stop, but to find out about mechanisms and determinants. My scholarly aims will be primary, but the questions I shall investigate derive their relevance also from the challenge to influence technological development, and to influence it for the 'better,' whatever that exactly mean.

This thesis builds on insights developed in the field of technology and innovation studies, including such different approaches as evolutionary economics (Nelson & Winter, Dosi, Clark, Arthur), the quasi evolutionary approach (Rip, Schot), the technical systems approach (Hughes), actor-network theory (Latour, Callon, Law), Social Construction Of Technology (Bijker, Pinch) and politics of technology (Winner, Noble, Braverman).[3] Despite major differences between these approaches, they are characterized by four common themes: [4]

- technological development is heterogeneous;
- (social) interactions play an important role in technological development;
- the behavior of actors is guided by socio-cognitive frames;
- technological development is cumulative and non-malleable.

More specifically, I will use the concept of 'technological regime,' as it has been developed and proved its usefulness in technology and innovation studies.[5] This concept enables me to attack the issue of continuity and change in technological development. While technological regimes enable particular forms of technical innovation, they constrain others. This can be illustrated by the quotation from Nader. As Nader suggests, for quite some time safety was not an important design criterion in the technological regime of automobiles. Innovations achieved by this regime did not primarily relate to safety. Transformation of the existing technological regime was required to make safety more important as a design criterion in automobile design and innovation. This transformation was initiated by outsiders, people not immediately involved in (decision-making about) automobile design.

Why did it take years before the actions and complaints of these people affected automobile design? The reason is that many actors play a role in bringing about the actual transformation of a technological regime. Transformation of a technological regime is usually the outcome of a complex process of transformation in which many actors are involved. The unfolding process of transformation will be enabled and constrained by the prior existing technological regime. The transformation to a technological regime where safer cars are designed is made possible by the existence of engineering capabilities to design safer cars. It is also enabled by the existence of companies looking for ways to fight decreasing sales. Such companies may choose to go for safer cars as a market strategy. If this strategy is successful, it will be imitated by other car producers, joined in their competitive game.

It is the evolution and the possible transformation of technological regimes that is the object of this study. To understand how technological regimes are transformed, I will relate the concept 'technological regime' to the general sociological theory of Boudon.[6] This enables me to conceptualize what I above called, in a common-sense way, 'processes of transformation.' The theory of Boudon will help me to conceptualize how processes of transformation set off. In particular, it suggests that this will happen when feedbacks from the environment of the regime are made manifest by outsiders. Therefore, I use the role of outsiders - people from outside the technological regime - as a particular research site to study processes of transformation.

The choice of this research site is relevant for two additional reasons. First, the literature suggests that outsiders play an important role in bringing about radical innovations that may help to transform technological regimes. Constant, in his 1980 book *The Origins of the Turbojet Revolution*, describes how outsiders to the existing aero-engine community created the turbojet revolution. The importance of outsiders in the development of radical innovations is also suggested by studies of Tushman & Anderson (1986) and Truffer & Dürrenberger (1997).

More generally, the dynamics of technological change is subject to developments outside technological regimes. Mol's recent study *The Refinement of Production* (1995) shows how general social transformations as highlighted by the ecological modernization theory are reflected in three sub-sectors of the chemical industry (paints, plastics and pesticides). Such transformations as the increasing importance of ecological criteria in the design of production processes, the growing participation of environmental NGOs in direct negotiations with economic agents and state representatives and the transformation from bureaucratic, top-down dirigism by government toward 'negotiated rule-making' are key factors in the dynamics of technological change in the chemical industry.[7]

Second, the choice of this research site links this study with recent work on the 'management of technology in society.' This ambitious phrase has been used to capture the thrust of Constructive Technology Assessment (CTA).[8] Schot & Rip (1996) have described the overall TA philosophy as 'to reduce the human costs of trial and error learning in society's handling of new technologies, and to do so by anticipating potential impacts and feeding these insights back into decision making, and into actors' strategies.'[9] The aim of CTA is described by them as follows: 'to broaden the design of new technologies (and the redesign of old technologies).

Feedback of TA activities into the actual construction of technology is crucial, and strategies and tools contributing to such feedback make up CTA.'[10]

This introductory chapter will be used to explain the central concepts underlying the thesis and to develop the research questions. Section 1.1 and 1.2 are devoted to a discussion of the two central concepts of this thesis: technological regimes and processes of transformation. In Section 1.3, I discuss how processes of transformation can be studied against the backdrop of existing technological regimes. In Section 1.4, the research questions are formulated. Section 1.5, finally, sets out the organization of the argument in the body of the thesis.

1.1 Technological Regimes

The notion of technological regime was introduced above as a shorthand for cumulative and patterned technological development and as a way to understand the difficulty of influencing technological development (by outsiders, or by any single actor). For it to be more than a label, it has to be operationalized and empirically located. I shall do this in two steps.

First, I propose a definition of technology (in line with recent literature) which combines the local work of developing new artefacts and systems with the knowledge and rules involved in such work and which are shared across locales. A technological regime is the integration of local work and the cosmopolitan, shared elements. Because such a regime transcends particular localities, it introduces a measure of homogeneity or patternedness in technological development.

Second, I specify in more detail the types of elements which make up a technological regime, and discuss its social locus, including the question of which actors can be considered to be inside the regime, or the interaction system spanned by the regime. This is a necessary preliminary to empirical study of regimes, but also conceptually important for the question of transformation of technological regimes, to be discussed in Section 1.2: what is exactly changing when a regime is transforming?

Technology has been conceptualized in many different ways and different conceptualizations are useful depending on the analytical aims.[11] The notion of technology I will employ in this thesis is that of technology as the alignment between technical configurations and functions. At the concrete level of the artefact, the alignment between technical configurations and functions is reflected in what Kroes has called the *dual nature of technological artefacts*.[12] An artefact is both a physical object with physical properties - a technical configuration - and it serves a function. Functions and technical configurations are aligned to each other in design processes. Studies of design processes have revealed how intended functions are translated into technical configurations.[13] Usually, design processes start with the formulation of design requirements and specifications on the basis of intended functions. As Goel emphasizes, the formulation of the design requirements must be seen as a first, provisional, ill-defined and very global representation of the artefact that will eventually be produced.[14] During the design process this global representation will

be reinterpreted, changed and translated into (artefact) representations that gradually become more concrete and well-defined, ending with a design drawing that functions as blueprint for the production process.[15] In the production and implementation process, further changes may well occur.
The translation of functions into working technical configurations is made with the help of knowledge and design tools. Such knowledge may be available as experience. From experience, designers know what kind of constructions will successfully fulfill certain functions and which will not. Knowledge and design tools also take more explicit and structured forms.[16]
If the forms of knowledge and the design tools used in local design processes are *shared* over different locales and if this results in a certain regularity in how functions and technical configurations are aligned in a specific technological domain one can speak of a *technological regime*.[17] Disco, Rip & Van der Meulen (1992) describe how such regimes come about. In doing so, they distinguish between - what they call - local and cosmopolitan technological regimes. For them

> *The concept of "local technological regimes" refers in an absolute sense to a situation in which design heuristics and production processes are entirely self-contained within local contexts (pre-eminently firms), such that outside sources of expertise and materials are not required for regular production or even innovation.*[18]

According to them, most local technological regimes cosmopolitized, *i.e.* they became more global (regional, national, international) in character, during the 19th century as increasingly information on technological development was exchanged, new institutions were established for the accumulation and processing of technological knowledge, and design tools like technical models became shared among actors. In most technological domains, inter-organizational division of design labor emerged and the behavior of 'local' actors became guided by inter-organizational rules. As they note:

> *While actual production is almost always already embedded in supplier-customer relationships and filières, the knowledge, skills and artifacts that go into the design of new products and production processes may seem to depend only on the capacity of the local situation. But the quality and scope of the knowledge and skills is non-local in origin, and is maintained (and often certified) in interaction with professional colleagues elsewhere. The artifacts built reflect widespread views on what is a good ship's hull, a good reinforced concrete viaduct, or a good radio*.[19]

What is crucial for the genesis of technological regimes is that actors at the local level interact and react to each other, creating interdependencies and so emergently a global level of artefacts, design tools, technical norms and the like which then enable and constrain further action at the local level. As a result, certain regular patterns of technological development are discernable. Although different authors have phrased it differently, this central idea underlies all current notions of technological regime,

as I will illustrate below.
Nelson and Winter were, in 1977, probably the first to use the notion of 'technological regime.' They relate the term to

> *technicians' beliefs about what is feasible or at least worth attempting. For example, the advent of the DC-3 aircraft in the 1930's defined a particular technological regime; metal skin, low wing, piston powered planes. Engineers had some strong notions regarding the potential of this regime. For more than two decades innovation in aircraft design essentially involved better exploitation of this potential; improving the engines, enlarging the planes, making them more efficient.*[20]

According to them,

> *The sense of potential, of constraints, and of not yet exploited opportunities, implicit in a regime focuses the attention of engineers on certain directions in which progress is possible, and provides strong guidance as to the tactics likely to be fruitful for probing in that direction. In other words, a regime not only defines boundaries, but also trajectories to those boundaries.*[21]

A technological regime, then, consists of certain design options and solutions and heuristics and trajectories (in the sense of promising routes to exploit potential) for further development of the technology. This definition of technological regime is comparable to the notion of *technological paradigm* developed by Dosi in analogy with Kuhn's concept of scientific paradigm.[22] A technological paradigm defines directions for further development, so-called *technological trajectories*.[23] Nelson & Winter's technological regime then consists of a technological paradigm and one or more technological trajectories. Van den Belt & Rip (1987) have further developed the Nelson-Winter-Dosi model. In doing so, they have specified the definition of, and relation between, technological paradigms and technological trajectories:

> *The occurrence of a technological paradigm can be characterized by the clustering of successful heuristics around an exemplary achievement, such as the DC-3 aircraft. Following Kuhn's terminology, we speak of an exemplar. The appearance of an exemplar is a necessary but not sufficient condition for "normal" technological development along a trajectory to occur. In addition, there have to be expectations about the success of continuing work within this cluster of heuristics - expectations that must be embedded in the subculture of technical practitioners and others involved in the development. Again borrowing from Kuhn's terminology, we can speak of the existence of a cultural matrix. The combination of exemplar and cultural matrix forms a technological paradigm, and the further articulation of such a paradigm, partly influenced by the selection environment, leads to a technological trajectory.*[24]

These definitions of technological regime and technological paradigm are also similar to notions used by the historians of technology Constant and Vincenti. Constant uses the concept of *normal technology*, whereas Vincenti speaks of *normal design*. For Vincenti, normal design is design in which the operating principle and the normal configuration of the artefact to be designed are taken for granted.[25] For Constant, normal technology is the improvement of an accepted technological tradition or its application under new, more stringent, circumstances.[26] Such technological traditions are embedded in technological communities:

> *Technological traditions of practice comprise complex information physically embodied in a community of practitioners and in the hardware and software of which they are masters. Such traditions define an accepted mode of technical operation, the conventional system for accomplishing a specified technical task. Such traditions encompass aspects of relevant scientific theory, engineering design formulae, accepted procedures and methods, specialized instrumentation, and often elements of ideological rationale. A tradition of technological practice is proximately tautological with the community which embodies it; each serves to define the other.*[27]

Note that Constant in this quote not only refers to design options and trajectories (heuristics) for the further development of a technology but also to such elements as design formulae and scientific theory, *i.e.* types of knowledge and design tools. So, the concepts used by Constant to describe regular technological development - normal technology, technological tradition - refer to a broader range of elements than Nelson & Winter's notion of technological regime. Such a broader conceptualization of regular technological development can also be found in recent definitions of 'technological regime.' Rip & Kemp (1998), for example, define a technological regime as follows

> *A technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems -- all of them embedded in institutions and infrastructures.*[28]

Kemp, Schot and Hoogma (forthcoming) give a somewhat similar definition. Like Rip & Kemp (1998), they stress the existence of *rules* by which the actors' behavior is constrained. They define a technological regime as

> *The whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructure that make up the totality of a technology. A technological regime is thus the technology-specific context of a technology which prestructures the kind of problem-solving activities that engineers are likely to do, a structure that both enables and constrains certain changes. Within this complex, the accommodation between its*

elements is never perfect, there are always tensions and a need for further improvement. The term regime is used rather than paradigm or system, because it refers to rules. Not just rules in the forms of a set of commands and requirements but also rules in the sense of roles and practices that are being established and that are not easily dissolved. Examples of such rules are: the search heuristics of the engineers, the rules of the market in which firms operate, the user requirements to be accommodated at any given time, and the rules laid down by governments, investors and insurance companies. Like a political regime or a regulatory regime, a technological regime contains a set of rules. These rules guide (but do not fix) the kind of research activities that companies are likely to undertake, the solutions that will be chosen and the strategies of actors (suppliers, government and users). The idea behind the technological regime is that the existing complex of a technology extended in social life imposes a grammar or logic for socio-technical change, the same way as the tax regime or the regulatory regime imposes a logic on economic activities and social behaviour.[29]

Underlying the notions of 'technological regime' discussed here, there is the central idea that elements of relevance for technological development like design options, heuristics and technical models are (actively) *shared* in technical domains and work as *rules* that guide the actions and interactions of the actors involved, resulting in certain *regular patterns of technological development*.

The concept 'technological regime' then is similar to the concept of 'regime' as it is used in political (and social) science to refer to 'a complex of interactions subjected to certain regularities or rules.'[30] Here, the concept of 'rule' refers to intersubjective and context-specific knowledge elements that provide the actors involved with strong arguments to behave in a particular way in a specific situation.[31]

The rules that are characteristic for a technological regime vary in form and content.[32] Some rules will be explicitly laid down in requirements and technical norms. Other rules will be tacit and implicit and will be followed by the actors on the basis of habits or tacit knowledge. Tacit rules may, for example, derive from technical models generally used in a technological regime. Sometimes, such tacit rules in the course of time become more articulated and will then be formulated as explicit design heuristics. Rules in technological regimes can also be embodied in production apparatus or technological artefacts.

Which kinds of rules make up a technological regime? Nelson & Winter (1977, 1982) mention design options and solutions and heuristics and trajectories for further development as the central elements of technological regimes. Van den Belt & Rip (1987) add exemplars and the matrix of expectations to the elements mentioned by Nelson and Winter. Disco, Rip & Van der Meulen (1992) emphasize those elements that are actively shared and enable coordination between the various actors involved in technological development. In particular, they discuss so-called technical models and technical hierarchies. (I will discuss these concepts in more detail in Chapter 2).

Rip & Kemp (1998) and Kemp, Schot & Hoogma (forthcoming) name a broader range of elements, which contain (interaction) rules.
Although there is some difference in emphasis between these authors with respect to the central elements of technological regimes, the different definitions are not mutually exclusive. The key point is that a technological regime contains (interaction) rules which are actively shared by the actors, enable coordination and so result in regular patterns of technological development.
In this thesis, all those elements that contain shared interaction rules with respect to the alignment between technical configurations and functions will be seen as part of technological regimes. By distinguishing between rules emphasizing function and rules emphasizing configuration, with the artefact as outcome, a *triangle of technological development* results (Figure 1.1). Elements on the left hand of the figure relate to functions and those on the right hand to technical configurations. This triangle synthesizes a large body of literature on design and technological innovation. It is inspired by Kim Clark's visualization of 'design hierarchy,' but adds two dynamic elements.[33] The first is the idea of overall guiding principles (Smit, Enserink), and the promise-requirement cycle (Van Lente).[34] The second is the open-ended character of the deceptively simple label 'artefacts' at the bottom of the triangle. Artefacts require their own alignment and repair work, and are never simple implementations of a recipe. Thus, the triangle encompasses a top-down, as well as a bottom-up dynamics: from goals, principles, promises and requirements to artefacts, and from the actual realization of artefacts and the problems (and sometimes new possibilities) involved to shifts in requirements and goals. So, the simple phrase 'alignment of function and technical configuration' covers complex processes, and the triangle details the linkages between experiences on location and the interactions and negotiations at the global level of the regime.

The different elements of the triangle can be described as follows:

- *Guiding principles* are general principles that relate the design of a technology

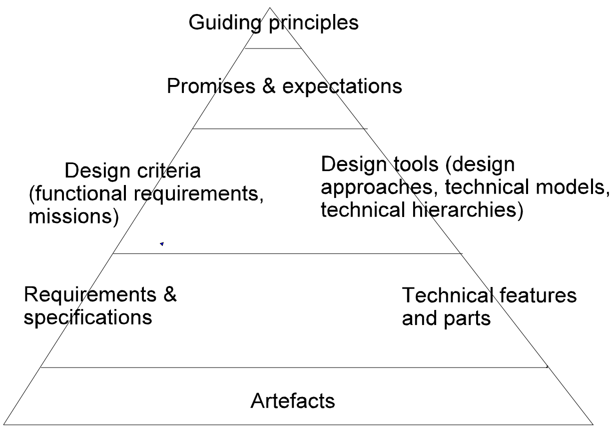


Figure 1.1 *The Triangle of Technological Development*

to doctrines and values and can thus be used to legitimate a technological regime and its outcomes.[35] They contain rules for the formulation of elements such as design criteria, and requirements & specifications.

- *Promises and expectations* about future technology will, when shared in a technological regime, be translated into more specific requirements for new technology and so guide the development of new artefacts embodying new alignments between technical configurations and functions.[36]

- *Design criteria* broadly define the kind of functions or functional requirements to be fulfilled by an artefact and the kind of boundary conditions that are important in the design of a technology.[37]

- *Design tools* are tools used in the design process including scientific knowledge. More specifically, the following kinds of design tools can be distinguished:[38]
  Design tools to translate functions into requirements;
  * *Design heuristics*, *i.e.* inter-subjectively sanctioned rules suggesting the direction in which a good solution to a design problem can be found;[39]
  * *Technical hierarchy*, the subdivision of the artefact to be designed in devices and components;[40]
  * *Technical models*, *i.e.* representations of a class of technical artefacts showing their (underlying) structure and function.[41] Technical models make design more flexible by making possible the conceptual generation of alternative designs. Technical models also suggest design heuristics;
  * Design tools to *evaluate* whether particular artefacts fulfill their intended function. These can be tools to enable tests (prototypes, test facilities), but also calculation and simulation tools;
  * *Design methods and approaches*, which guide the designer(s) through the different phases of the design process.

- *Technical features* and *component parts* are characteristics of artefacts as they are designed in technological regimes; usually they can be varied within existing technical models and technical hierarchies.

- *Requirements & specifications* are a specification of the general design criteria that are typical of a technological regime. The specifications are often formulated in quantitative terms.

- *Artefacts* are the embodiment of the alignment of functions and technical configurations that is typical for a technological regime. They should be conceived as imperfect embodiments of functions and more specific requirements & specifications.[42] Imperfection derives from the fact that usually not all requirements can be met at once. Such conflicts will often only become clear during the design process and attempts can be made to resolve these conflicts by the mobilization or the development of new technical means. In practice, however, at least some conflicts among requirements will in the end not

be resolved during the design process. So, compromises or *tradeoffs* among the requirements usually have to be accepted.
Artefacts are also imperfect because they always have properties that are not designed into them intentionally. These properties may manifest themselves when *secondary effects* occur. Secondary effects are consequences of artefacts that were not taken into account during design.[a] They may arise from intended properties of artefacts but also from the way artefacts are produced, used, maintained and disposed.

The different elements of the triangle of technological development are aligned to each other. If one of them is redefined, sooner or later, others have to change as well. Often such redefinitions can be achieved within the bounds of the existing technological regime because elements in the upper part of the triangle contain rules to change elements in the lower part. (This will be further elaborated in Chapter 2). Translations between the different elements of the triangle of technological development are made through what I will call processes of technical agenda building.[43] An example of technical agenda building is the promise-requirement cycle as described by Van Lente (1993). Initially, promises of new technology are formulated by individual actors. To exert influence, these promises have to become shared by other actors, *i.e.* they have to be taken up in the technical agenda of the regime or more localized agendas. If promises become part of the agenda, they demand attention and action of the involved actors and they will be translated into more specific requirements for new technologies.
While technical agenda building is important for the redefinition of the central elements of a technological regime, the design of artefacts, below in the triangle of technological development, has a dynamics that is somewhat independent from technical agenda building. This has two reasons. First, new artefacts may be designed before reformulations of the other elements of the triangle have become shared in the entire regime. Second, during design processes it may turn out that artefacts cannot meet all formulated requirements. In fact this is a common situation. As argued above, artefacts are best conceived as imperfect embodiments of requirements and specifications. Therefore, agreement among actors about requirements is not enough to achieve new artefacts and so a reformulation of the rules of the regime.

What is the *social locus* of a technological regime? Nelson & Winter (1977, 1982) locate a technological regime within the (changing) population of firms producing a particular technology. By speaking about ‘engineers’ belief,’ they also relate the term - although not explicitly - to the professional community of engineers. This community is central in Constant’s notion of normal technology. Like Constant (1987), Van den Belt & Rip (1987) stress that both firms and the community of

a The fact that secondary effects are not taken into account during the design process does not necessarily mean that they are completely unforeseen. As Winner stresses: ‘unintended consequences are not *not* intended’ (Winner, 1977, 97). It may simply be preferable to forget about them for the developers of technology.

engineers are important loci for technological development. Disco, Rip & Van der Meulen (1992) stress that divisions of design labor are essential for technological regimes, for example between universities and firms. Other authors are less explicit on this point, but the broad range of elements they cite as possible elements of a technological regime imply the involvement of governments, R&D laboratories, suppliers and users besides firms.

If technological development is the alignment of technical configurations and functions, the 'places' where this alignment is brought about constitute the social locus of a technological regime. This is often the 'firm.' However, the development of (new) technical configurations and the articulation of functions are also essential for technological regimes. These activities are related to elements in the upper parts of the triangle of technical development (Figure 1.1) and bring to the fore such actors as R&D institutes, universities, suppliers (primarily with respect to the development of technical configurations and design tools) and users and regulatory bodies (primarily with respect to the articulation of functions).

The question of the social locus of a regime is important when one has to decide who is inside the regime and who is outside. I will conceive all those actors who share rules with respect to the formulation of functions, the development of technical configurations and the alignment of functions and technical configurations as insiders to technological regimes. The notion of 'sharing' should be treated with some care. Since in technological regimes, divisions of (design) labor will exist, activities of the various actors are, to some degree, coordinated and 'mutually congruent.'[44] Certain interaction rules will exist, but these rules need not have the same meaning for all the actors involved.[45] The systems of interaction that span particular technological regimes have features of what the sociologist Boudon calls functional interaction systems, *i.e.* interaction systems that are a coordinated whole by virtue of the existence of a certain division of labor and various roles attuned to each other.[46] Some rules existing in a technological regime will then be role-specific while others apply to all actors in the regime.

Different roles existing in technological regimes will be discussed in more detail in Chapter 2. Here, the important point is that involvement in activities of the articulation of functions, the development of technological configurations and the alignment of functions and technical configurations defines membership of a technological regime.

1.2 Processes of Transformation

Technological regimes change over time. Gradually and incrementally, perhaps, and not as fast, or in the direction that critics would prefer, but they do change. Sometimes, there are radical changes. There is a large body of literature on incremental and radical innovation[47], but these studies are, in a sense, misguided, because they focus on individual innovations and their incrementalness or radicalness as the phenomenon to be explained, instead of focusing on how technological regimes enable particular innovations and constrain others, and on how limitations inherent in the regime are opened up sometimes.

Here, I can profit from the fact that technological regimes were defined in general sociological terms. Their specificity, as *technological* regimes, was taken into account (*cf.* the triangle of technological development), but the characterization in terms of rules shared across locations, which are binding on actors who want to remain within the regime, is quite general. Thus, it is possible to employ a general sociological framework; specifically, the framework developed by Boudon to study mutual dependency and functional systems of interaction. Boudon's theory is particularly useful, because it addresses the conditions under which such systems just reproduce themselves, innovate within the bounds of the system, or transform themselves.

Before setting out Boudon's framework, it should be noted that technological regimes are embedded in what Boudon, and other sociologists, have called systems of interaction.[a] The rules that make up the technological regime both guide the actions and interactions of the actors in the system of interaction, and are the outcome of that system of interaction. That is to say, rules are based on earlier interactions (they are an outcome) and constitute the basis for future interactions (they guide actions within the system of interaction).

Boudon distinguishes three types of processes of social change.[48] This classification can be applied to processes of technological change as well.

Boudon's classification of processes of social change is based on a general sociological scheme consisting of three elements: a system of interaction, its environment, and outcomes (Figure 1.2).[49] The system of interaction consists of actors with certain characteristics and certain relations among these actors (the structure of the situation). The environment consists of a number of actors, not immediately involved in the relevant system of interaction and economic, historical, institutional and technological givens. The third element is the outcomes produced by (the actors in) the system of interaction.

The arrows in Figure 1.2 stand for causal relations between the different elements.[50] According to Boudon, causal relations of type (A) and (B) can be found in any process of social change. The causal linkages of type (C), so-called feedbacks, may be absent in some processes of social change. The distinction between the three types of social change is based on the presence of such feedbacks (see Figure 1.3).

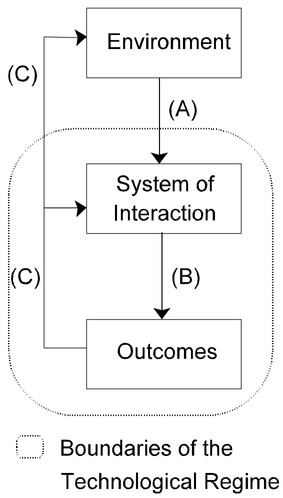


Figure 1.2 *Boudon's General Sociological Framework and Technological Regimes*

a In this thesis, I use the term 'technological regime' not only to refer to the rule-set with respect to the design and further development of a technology, but also sometimes as a shorthand for the system of interaction in which this rule-set is embedded.

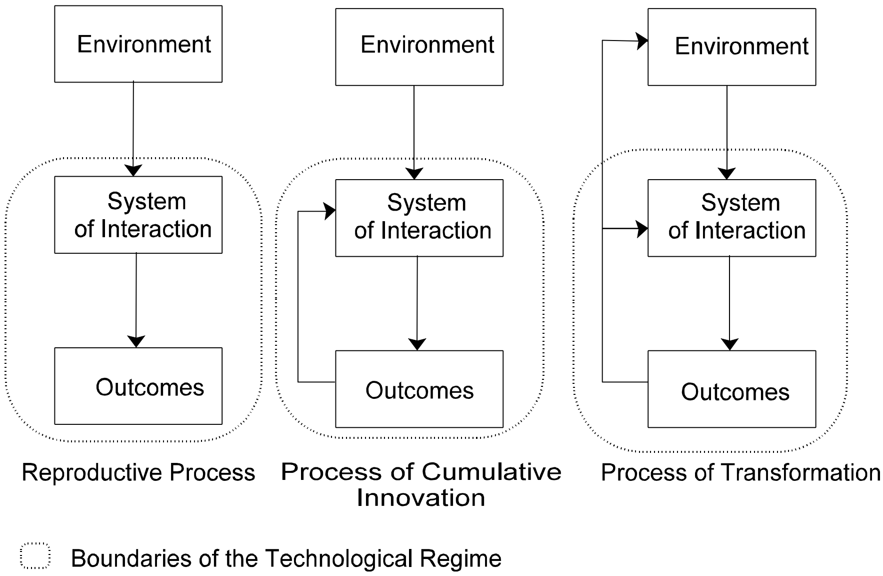


Figure 1.3 *Three Types of Processes of Social Change Distinguished by Boudon Applied to Technological Development*

If we take the alignment between technical configurations and functions as the main interaction outcome in which we are interested, the related processes of technological change can be described as follows.

Following Boudon's terminology, I will speak about reproductive processes if interaction outcomes are not fed back to the system of interaction.[51] In such a case, existing technical configurations and functions are continuously reproduced. The alignment of technical configurations and functions is static. The contents of the elements of the triangle of technological development (Figure 1.1) remain the same. Boudon speaks about cumulative processes if interaction outcomes are fed back to the system of interaction, while feedbacks with the environment are kept latent.[52] Such cumulative processes may take different forms; they may be truly cumulative, but also be oscillating. I will speak about processes of cumulative innovation if interaction outcomes are fed back to the interaction system leading to proposals for new technological configurations and functions, in such a way that new alignments between technological configurations and functions are brought about. Some elements in the triangle of technological development - especially those in the upper part of Figure 1.1 - remain stable while others - in the lower part - change according to certain patterns or trajectories. Which elements stay stable and which change according to what kinds of patterns is historically contingent and, therefore, depends on the particular regime under study.

Both processes, of reproduction and of cumulative innovation, are characterized by a regularity in the way technical configurations and functions are aligned. According to Boudon, these processes occur only in specific circumstances.[53] For reproductive processes, a minimal condition is that there are no feedbacks from the interaction outcomes either to the interaction system or to the environment, so that existing technical configurations and functions are continuously reproduced.

In processes of cumulative innovation, earlier interaction outcomes are fed back to the existing system of interaction leading to proposals for new technical configurations and functions. Thus innovation should take place so that new alignments between technical configurations and functions are brought about. This does not rule out that now and then radically new technical configurations or functions are proposed and realized, but the main pattern is one of cumulative technological development. A precondition for processes of cumulative innovation is that feedbacks from the environment are kept latent.

In essence, it are the rules of a technological regime that keep technological development coordinated and cumulative and feedbacks from the environment latent. These rules define the accepted way of designing a technology and exploiting trajectories for further development. So, they keep technological development coordinated and cumulative. Meanwhile, these rules define membership of the technological regime. Therefore, they keep feedbacks from the environment latent in the sense that actors not sharing the rules of a technological regime will not easily be accepted by regime insiders. Technological regimes then are characterized by technical closure (accepted ways of designing and further developing a technology) and social closure (who is to contribute, and in what way, to the design and further development of a technology?).[54]

Following Boudon, processes of transformation can now be defined as processes in which feedbacks from the environment of the technological regime become manifest (*cf.* Figure 1.3). Boudon distinguishes two mechanisms by which feedbacks from the environment can become manifest: aggression toward the environment or a demand upon the environment.[55]

In the case of aggression, the technological regime produces outcomes disliked by actors outside the technological regime and which make them intervene. Typical examples are secondary effects, *i.e.* effects of technology that were not taken into account during design and may be disliked by regime outsiders. An example is how the relatives of car victims protest against the insecurity of cars. Such outsiders may try to feed back the secondary effects to the existing technological regime so that regime insiders begin to feel forced to strive for certain changes in the technological regime so as to forestall these particular secondary effects in the future. In the case of aggression, either regime outsiders or regime insiders will propose and articulate particular strived-for-changes they think should be achieved in the regime.

In the case of demand, the technological regime produces outcomes disliked by certain insiders or it is characterized by certain problems, which cannot (easily) be solved by insiders themselves. A typical example for technological regimes is a demand upon outsider technologists for engineering capabilities to help solve particular design problems. Such a demand upon the environment usually follows on internal problems or tensions within the regime. These problems or tensions may be latent. As Kemp, Schot & Hoogma (forthcoming) note, technological regimes are usually characterized by some internal tensions. Outsiders can try to make latent problems and tensions manifest, creating a demand upon the environment of the regime. In the sixties and seventies, microbiologists for example argued that sewage treatment plants were not designed in an optimal way and that they possessed knowledge to overcome this problem in the technological regime of sewage treatment plants.[56] So, like in the case of aggression, a demand will result in either outsiders or insiders proposing and articulating particular strived-for-changes.

Boudon suggests that the manifestation of feedbacks from the environment of a system of interaction results in changes in that existing system of interaction, and its outcomes:

> *[T]ransformative processes are characterized by the existence of feedback effects from the outputs of the system, or the characteristics of the system of interaction on the system's environment. This action on the environment provokes, in turn, a modification of the system.*[57]

For technological development, this would mean that processes of transformation result in a transformation of the existing technological regime. Here, transformation is defined as disruption of the historically stabilized and accepted ways of designing and further developing a technology. Boudon only suggests that a causal link exists between feedbacks from the environment and the transformation of a technological regime. In addition, two arguments can be given why feedbacks from the environment can lead to a transformation of the existing technological regime.

The first argument is that feedbacks from the environment can be associated with the proposition and articulation of certain strived-for-changes in a technological regime by at least some actors, as the brief discussion of the mechanisms aggression and demand has shown. These strived-for-changes may result in a transformation of the prior existing technological regime if they become shared by several actors in the regime and begin to guide their behavior.

Strived-for-changes in technological regimes become shared through what political scientists have called agenda building.[58] Agenda building is the process in which particular issues reach the agenda of a technological regime or more local agendas. As Van Lente notes, the agenda 'contains those elements that orient actors and search processes by indicating priority and direction.'[59] 'An important feature of 'agenda' is its shared character.'[60] Issues or elements at the agenda are collective entities. 'They gain their importance, if not their existence, from being more or less shared within a research group, within a firm or community or within society as a whole.'[61] During agenda building, different actors compete to get their definition of the problem or issue at stake recognized and accepted.[62] The process of agenda building takes place in so-called *arenas* or *fora*, 'places' or 'spaces' where 'various issues are debated, negotiated, fought out, forced and manipulated by representatives.'[63]

Even if strived-for-changes become commonly shared in a technological regime, that is no guarantee that the regime will actually be transformed. Strived-for changes also have to be translated into new artefacts and other elements of the triangle of technological development. For these translations, *technical* agenda building and the actual design of alternative technologies are important (*cf.* the earlier discussion of the triangle of technological development).

The second reason why feedbacks from the environment may result in a transformation of the existing technological regime, is that they can, and will often, be carried by outsiders. During processes of transformation, outsiders may temporarily - or on a more structural basis - become involved in the relevant system of interaction and impinge on the definition of functions and technical configurations, and on their alignment. If this happens, social closure is broken up making it likely that technical closure will be broken up too.

Here, outsiders are defined as those people who do not share the rules existing in a technological regime. This definition is consonant with the one in Howard Becker's 1963 book *Outsiders; Studies in the Sociology of Deviance*. According to Becker, outsiders are people who behave in a deviant way.[64] There are two types of deviance. First, deviance can mean *rule-breaking behavior*. This type of deviance can in principle be recognized by the analyst on the basis of a reconstruction of the rules existing in a system of interaction. Second, 'deviance' is a *label* used by actors in a system of interaction. This type of deviance is also connected to the rules existing in a system of interaction, but here the analyst depends on the actors who interpret certain behavior as 'deviant.'

It may be hypothesized that in technological regimes, rule-breaking behavior will often be labeled as 'deviant' by other actors. This is related to a mechanism, which the sociologist Parkin has named *closure as exclusion.*[65] Within an interaction system, actors will try to exclude other actors, who do or may behave in a too deviant way. This is not to say that the limits of deviance are necessarily known to the actors in advance, but there may be a moment when an actor has 'gone too far' and has to face the counteraction of other actors, which may ultimately result in exclusion from the technological regime.

Attempts to exclude maverick actors from a technological regime may, however, fail. Moreover, rule-breaking behavior will not always be recognized or labeled as 'deviant' by other actors.[66] (This is why distinguishing the two types of deviance is important). One reason for this is that the rules existing in a technological regime may be ambiguous, disputed or inapplicable in a new situation. Another reason is that rules may conflict in particular situations. This ambiguous and sometimes contradictory character of rules creates room for 'strategic behavior' of actors. This is not to say that actors can behave as they want, but that the 'right' interpretation of the rules may be contested. Especially during processes of transformation, the kind of behavior accepted by the other actors in a technological regime is not simply given but a matter of ongoing interpretation and dispute.

This all implies that a particular rule-breaking behavior (labeled as such by the analyst) may eventually be accepted as 'normal' in a technological regime. This would imply a change in the rules existing in the regime. Such changes may in principle be brought about by initial outsiders, who perform rule-breaking behavior without knowing it. Changes may also result from the actions of (initial) outsiders who deliberately try to change the (interaction) rules and, so, the regime. Such actors may act as what Becker has called 'moral entrepreneurs,' people who try to

formulate and make authoritative new rules and, so, to change technological regimes.[67]
If one focuses on actors and their strategies, a straightforward picture results of moral entrepreneurs who can succeed or fail, and when successful, become moral custodians. Clearly, this is relevant to my question about continuity and change in technological regimes, but it does not exhaust the problem. At the level of regimes, other processes are also important. One immediate example derives from Petersen and Markle's analysis of controversies, where strategies of actors to mobilize support for their position expanded the conflict, included other actors, and thus shifted the agenda of the debate, so that the original actor was passed by.[68] In general, intentions and actions of actors are an input, but not a determinant of what happens at the collective level.

The discussion of both arguments shows that a link exists between feedbacks from the environment of a technological regime and the possible transformation of that regime. However, they also show that feedbacks from the environment are not a sufficient condition for actual transformation of a regime. Other mechanisms and dynamics at the collective level are important as well.

1.3 How to Study Processes of Transformation?

The object of this study is the evolution and possible transformation of technological regimes. On the basis of the conceptualization in the preceding sections, this general research interest can be translated into the more specific question; 'How are technological regimes transformed due to feedbacks from their environment?' To answer this question, it is not enough to observe what kind of feedbacks from the environment result in what kind of transformations. A technological regime is not an input-output system. Rather it exists in and by the (inter)actions of actors that in acting uphold or transform the technological regime. To study processes of transformation, we should trace how feedbacks from the environment encourage changes in the (inter)actions of the actors in the system of interaction that spans technological regime and how, subsequently, these changing (inter)actions amount to a transformation of the prior existing technological regime. What we should do then is to follow a *multilevel approach*, in which technological development is studied at, at least, two levels: the actor or local level and the structural or global level. Such a multilevel approach is in fact inherent to technological regimes. As explained before, the existence of technological regimes implies the creation of a global level of artefacts, technical models and the like that constrains and enables further action at the local level.
The multilevel approach is consonant with an important methodological principle in social science: methodological individualism. Probably the first sociologist to express the idea of methodological individualism was Max Weber. Here, I will adopt the notion of methodological individualism as it is outlined and defended by Boudon.[69] For Boudon, methodological individualism means 'that the sociologist must employ a method which considers individuals, or individual actors, included in

a system of interaction as the logical atoms of his analysis.'[70] This does not mean that we can never consider a social group, organization or institution as an actor but this is 'only legitimate in a case where a group is organised and explicitly provided with institutions which permit it to express collective decisions.'[71]
Methodological individualism does not imply an atomistic approach to social life. It 'in no way rule[s] out the phenomena of relationships (such as influence and authority) and indeed stress[es] that we need to understand an actor's behaviour with reference to a situation, which itself has been partly determined by macroscopic variables.'[72] Such macroscopic variables or phenomena make up the structure of the situation in which actors have to act and are recreated through the acting of actors. Methodological individualism then implies a multilevel approach.[73]

Following Coleman (1990), three types of relations between the actor and the structural level are important (see Figure 1.4). These are:

- The macro-to-micro relation (Arrow 1 in Figure 1.4). Here, the existing structure enables and constrains the behavior of actors.

- The micro-to-micro relation (Arrow 2 in Figure 1.4). Here, we need a theory or at least a conceptualization of the actions of individual actors;

- The micro-to-macro relation (Arrow 3 in Figure 1.4). Here, actions of individual actors add up to collective effects and changes at the structural level;

Processes of transformation will now consist of an interplay between changes at the structural level and the actor level (the dotted arrows in Figure 1.4). If feedbacks from the environment of the regime become manifest, this implies a change at the structural level. This will encourage changes in the behavior of individual actors. These changes will subsequently add up to changes at the collective level that in turn will encourage changes in the behavior of individual actions, etcetera. In this way, feedbacks from the environment may, via a number of subsequent steps, transform the existing technological regime. It may, however, also well be that the feedback from the environment is 'absorbed' during the process and that no transformation of the regime takes place.

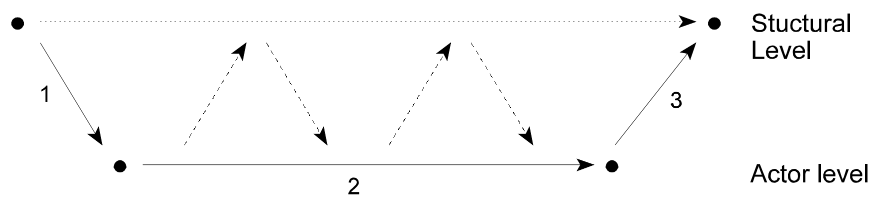


Figure 1.4 *Relation Between Actor and Structural Level (Based on Coleman, 1990)*

The Structural Level; Interdependencies and Roles in Technological Regimes

Like in any system of interaction, actors in a technological regime are dependent on each other for the achievement of certain goals. Following Boudon, we can make a distinction between direct interdependencies and indirect interdependencies among actors.[74] An example of a direct dependency is a person wanting to buy a bicycle from a cycle dealer. To achieve his goal, he is immediately dependent on the cycle dealer, with whom he can negotiate directly.

An example of an indirect dependency is when the federal bank of the USA wants to stabilize the price of the dollar. The bank can try to do this by selling or buying dollars, but the price of the dollar will also be dependent on the - hard to predict - actions of a whole range of other actors. The dollar price is not controlled by one actor, but the emergent result of the actions of many actors; it is an aggregation effect. Given the large range of actions relevant for the dollar price, it is impossible for the federal bank to cooperate or negotiate with all other relevant actors. Moreover, the federal bank does not need the direct cooperation of all these actors to sell or buy dollars. Nevertheless, to achieve a stabilization of the dollar price, the federal bank stays indirectly dependent on the actions of other actors.

Indirect dependencies exist in any situation in which the actions of various actors combined with the structure of the situation produce outcomes that are beyond the control of any of the individual actors. Especially the structure of the situation is important for the kind of aggregation or emergent effects produced. According to Boudon, structures of interdependency

> *... serve to generate emergent effects (effects which are not among the actors' objectives) which can take varied forms. Certain of these structures magnify the objectives of the agents, other overturn them, still others respect those objectives but produce undesirable deferred effects. Certain structures produce collective states of tension which do not result from antagonistic interests. Others indirectly produce collectively positive effects which the agents would be unable to realise if they tried to achieve them directly. Others again are responsible for global social change taking the form of genuine collective innovations.*[75]

Role-relations between actors in a technological regime are a second important feature. 'A role is defined by the group of norms to which the holder of the role is supposed to subscribe.'[76] Roles coordinate the behavior of actors vis-à-vis each other because of mutual role expectations and predictability of the actions of other actors.[77] This does not imply that roles simply prescribe the behavior of actors. Roles define 'an area of obligations and constraints that corresponds to an area of conditional autonomy.'[78]

Roles are mutually defined, and may depend for their definition and maintenance on an organizational framework. Prototypical examples are the relation teacher-pupil and the relation director-subordinate. In both cases, an overarching organization exists that - to an important extent - defines the roles. The existence of an overarching organization is, however, not necessary to speak of roles. Take for example the relation between governmental bodies and industrial firms. Here, no explicit overarching organizational framework exists. Both types of actors, nevertheless, subscribe to a set of rules in their behavior vis-à-vis each other and both have mutual expectations about the behavior of the other(s) that are based on such rules. There is no principal difference with the relation between teacher and pupil. The concept of role can then be applied to any situation in which interactions among actors (individuals or organizations) are organized by certain actor-specific rules, which are known to the other actors, so that actors have mutual expectations of each other's behavior.

Roles in technological regimes may be an emergent outcome of historically evolved divisions of (design) labor in those regimes. They may also be deliberately created. Boudon suggests that actors in an interaction system (technological regime) will try to create roles to forestall aggregation effects which are negative for (almost) all of them:

> *[T]he passage from an unorganised system to an organised system is often due to the desire shown by the social agents to eliminate undesirable emergent effects. It is clear, on the other hand, that a process of organisation inevitably implies the introduction of norms and constraints restraining individuals' margins of autonomy and leading to the inclusion of categories of action in roles.*[79]

According to Boudon, interaction systems in which the behavior of actors is constrained by the existence of such roles are less often characterized by aggregation or emergent effects than systems in which no roles exist.[80]

Roles may also be created at the global level of a technological regime. That is to say, some actors may develop an interest in the long-term viability of the regime as a whole and try to shape the regime as a whole. Typical examples of such actors in technological regimes are standardization institutions and professional organizations of engineers.

Interdependencies and role-relations between actors together constitute the structure of the interaction system that spans the technological regime. In Chapter 2, I will discuss four types of structures that technological regimes may have. I will call those structures *innovation patterns* because they help to achieve and maintain particular patterns of technical innovation. The four innovation patterns that I will distinguish are the R&D-dependent innovation pattern, the supplier-dependent innovation pattern, the user-driven innovation pattern and the mission-oriented innovation pattern. In the first two of these patterns, technical innovations primarily start with proposals for new technical configurations. When new technical configurations primarily spring from (scientific) ideas and concepts developed in R&D laboratories and institutes, there is an R&D-dependent innovation pattern. A second case is when new technical configurations are primarily based on new component parts developed by suppliers. R&D may here also play a role but more indirectly, *i.e.* via the supplier, so there is a supplier-dependent innovation pattern. The other two patterns start with the formulations of functions, primarily either by users (user-driven innovation) or by the government as client, financier and regulator (so-called mission-oriented innovation).

Innovation patterns are situated at the structural level in Figure 1.4. They describe similarities in structure as they may exist between different technological regimes. As far as innovation patterns do not change during processes of transformations, they will continue to enable and constrain the (inter)actions of the relevant actors during processes of transformation and determine how changes in those (inter)actions add up to a transformation of the prior existing technological regime. As shorthand, we can say: existing innovation patterns in technological regimes enable and constrain processes of transformation.

Action at the Individual Level and the Explanation of Processes of Transformation

Individual social action is conceived as purposive and as adaptational with respect to the situation in which the actor has to act. This notion of social action is explicitly or implicitly used by most social theorists and in many commonsense interpretations of our own behavior and that of others.[81]

To understand the actions of individual actors (persons as well as organizations), the Weberian method of *comprehension* or *verstehen* can be employed. ‘For Weber, to understand an individual action is to acquire sufficient means of obtaining information to understand the motives behind it. In his view, observers understand the action of an observed subject as soon as they can conclude that in the same situation it is quite probable that they would act in the same way.’[82] This idea of comprehension ‘implies the ability of the observer *to put him or herself in the actor’s place*, but does not in any way imply that the actor’s subjectivity is immediately transparent. Being able to put oneself in someone else’s place indicates a relationship, that of empathy, that can exist between two people however great the spatial or temporal distance between them.’[83]

Comprehension should not only focus on the motives of the actor, but also on the situation in which the actor has to act: social action is seen as adaptational given a certain interaction situation.[84] As Boudon notes, ‘*explanation* (of structure) and *comprehension* (of the actions of the subjects under observation) are quite inseparable aspects of the analysis.’[85] A good way to combine the aspects of explanation (of structure) and comprehension (of the action of actors) is through case studies as I will do. In the empirical Chapters 4 through 7, I will give a thick description of eight cases of processes of transformation.

1.4 Research Question and Research Methodology

To study how technological regimes are transformed due to feedbacks from their environment, I study processes of transformation against the backdrop of existing technological regimes. Outsiders will initiate processes of transformation in reaction to - outcomes of - existing technological regimes. Moreover, existing technological regimes will enable and constrain the unfolding of processes of transformation.

Given the research aim and focus, two specific research questions will be posed. The first relates to how existing technological regimes enable and constrain processes of transformation. That this will happen has been made plausible in general terms, but is important to be more specific. As indicated in the preceding section, four types of structures or innovation patterns of technological regimes can be distinguished: the R&D-dependent innovation pattern, the supplier-dependent innovation pattern, the user-driven innovation pattern and the mission-oriented innovation pattern. Presumably, these four different innovation patterns will enable and constrain processes of transformation in different ways. The first research question then is:

> *In what specific ways do the four innovation patterns (the R&D-dependent innovation pattern, the supplier-dependent innovation pattern, the user-driven innovation pattern and the mission-oriented innovation pattern) enable and constrain processes of transformation?*

I will answer this question by studying eight cases, two of each innovation pattern (see Table 1.1). I have chosen to carry out case studies because processes of transformation are complex contemporary phenomena. To unravel how they are enabled and constrained by existing innovation patterns, they should be studied against the background of existing technological regimes (Section 1.3). In other words, they should be understood in their real-life context. Moreover, because the prior existing technological regime, and its innovation pattern, may change during a process of transformation, the boundaries between the phenomenon and its context are not clearly evident. For such types of phenomena, case studies are the adequate research strategy. As Yin (1989) has pointed out, a case study 'investigates a contemporary phenomenon in its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used.'[86]

I will carry out a multiple case study to make comparisons between the cases about how different innovation patterns enable and constrain processes of transformation differently. The way I have selected my cases, two of each innovation pattern, reflects what Yin (1989) has called a *replication logic*: a case is 'selected so that it either (a) predicts similar results (a *literal replication*) or (b) produces contrary results for predictable reasons (a *theoretical replication*).'[87] Cases with the same innovation pattern are presumed to enable and constrain processes of transformation in similar ways, while cases with a different innovation pattern will do so in different ways. If the cases indeed show this, it can be claimed that the hypothesis that different innovation patterns enable and constrain processes of transformation in different ways is replicated and so confirmed by the empirical outcomes. If it turns out differently empirically, this will still enhance our understanding.

The selection of the cases will be explained in more detail in Chapter 3. There, I will also check whether the cases indeed are representative of the innovation pattern for which they were selected. In the Chapters 4 through 7, I will give a thick description of the cases. I will not describe the existing technological regimes extensively in terms of the elements of the triangle of technological development and involved actors, but focus on how the prior existing innovation pattern in each case enables and constrains the process of transformation. Further, I will make comparisons between cases with the same (initial) innovation pattern and cases with a different (initial) innovation pattern to unravel how different innovation patterns enable and constrain processes of transformation in different ways. In evaluating and comparing how the four innovation patterns enable and constrain processes of transformation, I will call particular characteristics of the innovation patterns opportunities, or constraints, as far as they help to achieve transformation of the prior existing regime in response to feedbacks from the environment.

While the first research question might be answered by highlighting only particular outcomes of the case studies, I have chosen to give a thick description of the cases in order to gain more insight in the dynamics of processes of transformation.
From Boudon's conceptualization of processes of transformation, it follows that two mechanisms will presumably be central in making feedbacks from the environment manifest and in setting off processes of transformation: aggression and demand. As

Table 1.1 *Case Studies Carried Out*

Existing innovation pattern	Cases
Supplier-dependent innovation pattern	*Household refrigerators*: The transformation toward refrigerators with environmentally sustainable coolants
	Paints: The transformation toward more environmentally sustainable paints
User-driven innovation pattern	*Chicken husbandry systems*: The transformation toward more 'humane', 'animal benign' chicken husbandry systems
	Sewage treatment plants: The transformation toward a larger role for biotechnology in the design of sewage plants
Mission-oriented innovation pattern	*Coastal barriers*: The transformation toward the incorporation of ecological design criteria
	Waterside bank constructions: The transformation toward 'natural' banks and the incorporation of ecological design criteria
R&D-dependent innovation pattern	*Aero-engines*: The transformation toward more 'silent' aero-engines
	Nuclear reactors: The transformation toward 'inherently safe' nuclear reactors

argued in Section 1.2, the occurrence of these mechanisms is not a sufficient condition for the transformation of a technological regime. The mechanisms aggression and demand can therefore only partly explain the dynamics of processes of transformation. For this reason, I have formulated my second research question as follows:

> *How can the dynamics of processes of transformation be understood? or, more specifically, via what routes or mechanisms are technological regimes transformed in the case of aggression toward the environment or in the case of a demand upon the environment?*

In each of the individual cases, I will trace in which ways technological regimes are transformed as a result of either aggression toward the environment or a demand upon the environment. By giving a thick description of each case, it is possible to trace new routes and mechanisms in addition to those that have been articulated before as part of the conceptual framework.

In addition to these two research questions, there is a recurring concern about the possibilities for change of technological regimes in desirable directions. My development of Boudon's theory allows me to specify this concern as a question about routes or mechanisms of transformation. This cannot be a full answer to the concern about possibilities for change, which also has to do with actor strategies and their outcomes, and with the articulation of what is desirable. My analysis allows me to reflect on these further issues in the epilogue.

Methodological Background

How can more general conclusions be drawn from the multiple case study that I will carry out? Case study results cannot be generalized on the basis of statistical generalization.[88] There, the researcher gathers a representative sample of data or respondents from a larger pool of data or respondents. Generalization is based on the representative character of the sample in relation to the larger pool. For case studies, this sampling logic does not apply. Studying enough cases that they constitute a representative sample is usually practically impossible.

Generalization of case study results should therefore be based on analytical grounds. Yin (1989) calls this alternative way of generalizing *analytical generalization.* In it, 'a previously developed theory [or conceptual framework, IvdP] is used as a template with which to compare the empirical results of the case study. If two or more cases are shown to support the same theory, replication may be claimed.'[89] For successful analytical generalization, case selection should follow a theory-driven replication logic.[90] As indicated above, I followed this logic but decided to refrain from the formulation of more specific hypotheses about how the four innovation patterns enable and constrain processes of transformation because no other research on this specific topic is available on the basis of which hypotheses could be formulated. Instead, I decided to infer how the four innovation patterns enable and constrain processes of transformation on the basis of my cases.

Case selection followed a replication logic with respect to the first research question.

With respect to the second, this was not possible, partly because this is a more open question. Moreover, I selected my cases already with respect to the first research question. Still, analytical generalization of the empirical findings with respect to this question is possible, albeit in a somewhat different way than in the case of a replication logic.

To understand how results with respect to the second research question can be analytically generalized it is important to realize that analytical generalization is primarily led by explanatory considerations. In each of the individual cases, I can and will search for mechanisms that explain the phenomena that I am studying. Subsequently, these mechanisms can be related to my more generally formulated conceptual framework and to concepts from literature. As far as I am able to do so in a way that explains my cases and contributes to a coherent conceptual framework, analytical grounds exist to generalize the results of the case study to some broader domain.

Analytical generalization in this broad sense is related to a method known as *Inference to the Best Explanation*.[91] Central to *Inference to the Best Explanation* is the search for different possible or potential explanations, which if true would explain the observed phenomenon. Subsequently, two criteria play a role in selecting from those potential explanations. The first criterion is that of likeliness; is the explanation likely to be true? The second criterion is that of loveliness; does the explanation - if true - add to the (potential) understanding of the phenomenon? The latter criterion does not require an explanation to be true or likely, it asks whether the explanation would add to the understanding of the phenomenon *if* it were true.[a] The claim with respect to this criterion is that 'the explanation that would, if true, provide the deepest understanding is the explanation that is likeliest to be true.'[92]

Like analytical generalization, *Inference to the Best Explanation* is led by explanatory considerations. It helps us to relate our empirical findings to mechanisms or theories that are more generally applicable. *Inference to the Best Explanation* thus helps us to structure our empirical material so we can (later) apply analytical generalization.

1.5 Outline of the Study

In *Chapter 2*, I will discuss a number of conceptual tools for the analysis of technological regimes and processes of transformation. In particular, I discuss four types of structures or innovation patterns that technological regimes may have and that are important for how technological change is achieved in technological regimes. These patterns are the supplier-dependent innovation pattern, the user-driven innovation pattern, the mission-oriented innovation pattern and the R&D-

a According to Lipton (1991), criteria of likeliness are to play some role in selecting (potential) explanations, but what sets *Inference to the Best Explanation* apart, according to him, is the striving for lovely explanations. Lipton gives the following more specific criteria for loveliness: the specification of a mechanism, preciseness, and contribution to the unification of the overall explanatory scheme (Lipton, 119).

dependent innovation pattern.

Chapter 3 discusses the selection of the cases and the data-gathering for the cases. On the basis of data gathered, it will be shown that the selected cases are instances of the four innovation patterns described in Chapter 2.

Chapters 4 to 7 each discuss two case studies with the same initial innovation pattern. Each chapter describes two processes of transformation narratively. In each chapter, I am especially interested in similarities and differences between the cases on the basis of which inferences can be made about the ways in which the particular innovation patterns enable and constrain processes of transformation. In each of the empirical chapters, such inferences will be made in the concluding sections of the chapter. If appropriate, I will also make inferences about the general dynamics of processes of transformation. Chapters 4 till 7 are organized in such a way that the more complex cases come at the end, so that the discussion of these cases can profit from insights presented in the earlier case studies.

Chapter 4 discusses processes of transformation in the technological regimes of household refrigerators and paints. Both processes of transformation started when certain outsiders began to protest against negative environmental effects produced by the technologies designed in the existing technological regimes. These regimes had a supplier-dependent innovation pattern. The chapter shows that this innovation pattern was enabling for the processes of transformation because suppliers had an eye for long-term developments and proactively developed particular technical alternatives in the expectation of regulation by the government. The availability of these alternatives enabled actual regulation by the government, which was an important route for the feedback of negative environmental effects and their translation into the new design criterion of environmental sustainability. Chapter 4 also shows that the supplier-dependent innovation may be particularly constraining for the development of innovations that do not fit the (long-term) interests of suppliers or their R&D capabilities and trajectories.

Chapter 5 discusses processes of transformation in two technological regimes with a user-driven innovation pattern: chicken husbandry systems and sewage treatment plants. In the case of chicken husbandry systems, the processes of transformation set off due to the aggression of the existing technological regime. In response to the neglect of animal welfare, animal welfare groups urged the design of welfare-augmenting chicken husbandry systems.
In the case of sewage treatment plants, the process of transformation was set off due to a demand upon microbiologists and, later, biotechnological researchers. Both groups did not yet play a role in the technological regime of sewage treatment plants, but they possessed relevant knowledge and could therefore argue that they should play a role in this regime.
In technological regimes with a user-driven innovation pattern, technical alternatives can be developed and become accepted via functional requirements formulated by users. This enables processes of transformation because feedbacks from the

environment may in different ways result in a reformulation of the functional requirements of users. In the meantime it is a constraint for successful transformation of the prior existing regime because if functional requirements are not changed, no alternatives come available - unless the innovation pattern is (temporarily) circumvented or changed - and so no new options for action are created that may, via a number of successive steps, result in the transformation of the prior existing regime.

Chapter 6 discusses two processes of transformation in technological regimes with a mission-oriented innovation pattern: coastal barriers and waterside banks. In both regimes, a process of transformation was initiated when outsider groups started protesting against negative ecological effects. Both processes of transformation eventually resulted in the effectuation of a new design approach and a demand upon ecologists and biologists.
Whereas in technological regimes with a user-driven innovation pattern, transformations will usually result from (provoked) changes in the functional requirements of users, in regimes with a mission-oriented innovation pattern, they will result from newly formulated missions. The fact that a limited group of actors controls the formulation of missions is both enabling and constraining. It is constraining because these actors are in a relatively good position to block the reformulation of the mission and the development of technical alternatives. It is enabling because once a new mission is formulated it will be implemented relatively effectively.

Chapter 7 discusses processes of transformation in the technological regimes of aero-engines and nuclear reactors, regimes with an R&D-dependent innovation pattern. In the case of aero-engines, airport neighbors and environmental groups protested against the noise of aircraft and aero-engines, eventually resulting in the development of more silent aero-engines. In the case of nuclear reactors, the striving for a new safety philosophy with respect to nuclear reactors, inherent safety, was advocated by a group of maverick nuclear scientists in response to public protests and to growing internal problems in the regime.
The R&D-dependent innovation pattern was enabling for the studied processes of transformation because R&D institutes and industrial R&D laboratories proactively undertake R&D efforts in anticipation of future social trends or future generations of nuclear reactors and aero-engines. The focus on technical newness that is typical for regimes with an R&D-dependent innovation pattern can also be a constraint. This focus may well lead to a technological fix, *i.e.* an attempt to solve certain problems that are partly social and institutional in nature by technical means alone.

In *Chapter 8*, conclusions are drawn on the basis of the empirical research. The findings from the empirical chapters are placed in the conceptual framework developed in Chapter 1 and 2. This results in a description of the different mechanisms that can be used to describe and explain the dynamics of processes of transformation against the background of existing technological regimes.

The final chapter is an *epilogue* that discusses how the insights generated in this thesis might contribute to 'better technologies in a better society.'

Notes to Chapter 1

1 OECD (1992).

2 Pinch & Bijker (1984). See also Bijker (1990 and 1995a).

3 See Arthur (1988, 1996), Van den Belt & Rip (1987), Bijker, Hughes & Pinch (1987), Bijker (1990, 1993, 1995a), Bijker & Law (1992), Callon (1986, 1987, 1992), Clark (1985), Dosi (1982), Dosi *et al.* (1988), Hughes (1983 and 1987), Kemp, Schot & Hoogma (forthcoming), Latour (1987), Law & Callon (1988), Mayntz & Hughes (1988), Nelson & Winter (1977, 1982), Noble (1977 and 1984), Pavitt (1984), Pinch & Bijker (19984), Rip (1992), Rip, Misa & Schot (1995), Rip & Kemp (1998), Roland (1992), Schot (1991, 1992) and Winner (1977 and 1986).

4 *Cf.* OECD (1992), Van Lente (1993) and Rip & Kemp (1998).

5 Nelson & Winter (1977, 1982), Disco, Rip & Van der Meulen (1992), Rip & Kemp (1998), Kemp, Schot & Hoogma (forthcoming).

6 Boudon (1981, 1986).

7 Mol (1995, 58).

8 Rip, Misa & Schot (1995), Schot (1996) and Schot & Rip (1996).

9 Schot & Rip (1996, 251).

10 Schot & Rip (1996, 252; note left out).

11 *Cf.* Rip & Kemp (1998). They conclude that 'configurations that work' is the basic conceptualization for technology as things or artefacts. The other main meaning of technology, how to make configurations that work (and how to make them work) is not thematized in their synthesis of literature, even while they acknowledge its importance.

12 See, for example, Kroes (1996).

13 *Cf.* Blessing (1996); Bucciarelli (1994); Cross (1989); Goel & Pirolli (1989); Goel (1992); Henderson (1991 and 1995); Kroes (1996); Petroski (1982); Pye (1964); Roozenburg & Cross (1991); Schön (1983 and 1992); Stauffer, Ullman & Dietrich (1987); Ullman, Stauffer & Dietrich (1987); Vincenti (1990); Visser (1990).

14 Goel (1992) and Goel & Pirolli (1989).

15 *Ibid.*.

16 Vincenti has identified the following kinds of knowledge that are used in designing: fundamental design concepts; criteria and specifications; theoretical tools; quantitative data; practical considerations and design instrumentalities (Vincenti, 1990, 208).

17 According to Disco, Rip & Van der Meulen (1992, 495), '[t]here must be some active sharing, some coordination and some standardization of knowledge, skills and artifacts' to speak about a technological regime.

18 Disco, Rip & Van der Meulen (1992, 467, note left out). As they stress, such self-containment, at best, is relative. Some dependence on actors outside the firm always exist.

19 *Ibid.*, 495.

20 Nelson & Winter (1977, 57). They refer to Miller & Sawers (1968) and A. Phillips, *Technology and Market Structure* (Heath Lexington, 1973).

21 Nelson & Winter (1977, 57).

22 Dosi (1982). On technological paradigms, see also Gutting (1984).

23 Dosi (1982, 152).

24 Van den Belt & Rip (1987, 140); note left out.

25 Vincenti (1990, 1992).

26 Constant (1980, 1984, 1987).

27 Constant (1980, 10).

28 Rip & Kemp (1998, 340).

29 Kemp, Schot & Hoogma (forthcoming, 8).

30 Spier (1995). For a more elaborate conceptualization of regimes see Huizenga (1993a and 1993b). The basic idea that certain complexes of interactions are subjected to certain rules can also be found in Howard Becker's book on *Art Worlds*. According to him, art worlds are characterized by the existence of certain conventions. The role conventions play in art world is comparable to the role rules play in regimes. According to Becker, '[c]onventions place strong constraints on the artist. They are particulary constraining because they do not exist in isolation, but come in complexly interdependent systems, so that one small change may require a variety of other changes. A system of conventions gets embodied in equipment, materials, training, available facilities and sites, systems of notation, and the like, all of which must be changed if any one component is' (Becker, 1982, 32). Like technological regimes, art worlds are characterized by a division of labor: 'Each kind of person who participates in the making of art works ... has a specific bundle of tasks to do. Though the allocation of tasks to people is, in an important sense arbitrary - it could have been done differently and is supported only by the agreement of all or most of the other participants - it is not therefore easy to change. The people involved regard the division of tasks as quasi-sacred, as "natural" and inherent in the equipment and the medium' (Becker, 1982, 11-13).

31 Huizenga (1993a, 99).

32 *Cf.* Huizenga (1993a, 89-141).

33 Clark (1985).

34 Smit (1993); Enserink (1993); Van Lente (1993).

35 Smit (1993); Enserink (1993). See also Van de Poel (1998).

36 Van Lente (1993).

37 I use design criteria in a meaning that is comparable to what Hutter (1988) calls 'evaluation criteria.' As he points out evaluation criteria have a somewhat different meaning for the different actors involved. Nevertheless, they have also a common meaning and, therefore, link the activities of researchers, designers and managers and developments in the market.

38 *Cf.* Van de Poel (1993).

39 Disco, Rip & Van der Meulen (1992).

40 Vincenti (1992), Constant (1980), Disco, Rip & Van der Meulen (1992), Goel (1992). See also Clark (1985).

41 Disco, Rip & Van der Meulen (1992).

42 Van de Poel (1996). See also Pye (1964), Kroes (1996),Wynne (1988), Beder (1990), Petroski (1982), Martin & Schinzinger (1988, 64-70).

43 Technical agenda building is a specification of the general concept agenda building. For the latter, see note 58.

44 For the idea of congruency, see Grin & Van de Graaf (1996)

45 For a critique of the idea that successful design requires explicit agreement and mutual understanding between the actors involved in the design process, see Konda (1992). See Van de Poel (1994) for a critique of the idea - which can be found in Bijker's work - that technological normality or stability is always the result of shared meaning attributed to a technical artefact. It may be enough that the actions of actors are tuned to each other or are mutually congruent. A concept which is useful to describe elements which are shared by actors, but to which, nevertheless, not all actors necessarily attribute the same meaning, is the concept 'boundary object' developed by Leigh Star. Boundary objects are 'objects which are both plastic enough to adapt to local needs and the constraints of several parties emplacing them, yet robust enough to maintain a common identity across sites' (Star & Griesemer, 1989, 393). *Cf.* Also Hård (1993).

46 Boudon (1981, 39-57).

47 See Rip & Kemp (1998) for an overview.

48 Boudon (1981).

49 *Ibid.*, 95.

50 *Ibid.*, 94-96.

51 *Ibid.*, 97-107.

52 *Ibid.*, 97 and 108-123.

53 Boudon (1986).

54 *Cf.* Disco (1990). For the concept of closure see also Bijker (1990 and 1995a).

55 Boudon (1981, 128).

56 For details, see Chapter 5.

57 Boudon (1981, 123); emphasis added.

58 See, for example, Kingdon (1984). For application of the concept to technology studies, see, for example, Albert de la Bruhèze (1992) or Van Lente (1993).

59 Van Lente (1993, 9).

60 *Ibid.*

61 *Ibid.*

62 Albert de la Bruhèze (1992, 17).

63 Strauss (1978, 124). See also Albert de la Bruhèze (1992, 16).

64 Becker (1963).

65 Parkin (1974).

66 Reversely, non rule-breaking behavior may sometimes be labeled as 'deviant.'

67 Becker (1963, 147).

68 Petersen & Markle (1981).

69 Boudon (1981 and 1986).

70 Boudon (1981, 36).

71 *Ibid.*, 37.

72 Boudon (1986, 55-56).

73 *Cf.* Coleman (1990).

74 *Cf.* Boudon (1981, 66).

75 Boudon (1981, 84).

76 *Ibid.*, 40.

77 Boudon & Bourricaud (1989, 308).

78 *Ibid.*.

79 Boudon (1981, 60).

80 *Ibid.*.

81 Coleman (1990, 13).

82 Boudon (1986, 31); emphasis in original. Actions which are *comprehensible* in the Weberian sense may be seen as rational, in the widest sense of the latter term (Boudon, 1986, 51). Note that this notion of rationality is *situation-specific* (*cf.* Boudon, 1986, 46-51).

83 *Ibid.*, 51, emphasis in original.

84 *Ibid.*, 30.

85 *Ibid.*, 38, emphasis in original.

86 Yin (1989, 23).

87 *Ibid.*, 53, emphasis in original.

88 *Ibid.*.

89 *Ibid.*, 38.

90 *Ibid.*, see also Hoppe, Van de Graaf & Besseling (1995).

91 The account of *Inference to the Best Explanation* is based on Lipton (1991).

92 Lipton (1991, 63).

2

Technological Change in Technological Regimes

Innovation Patterns

In Chapter 1, a conceptual framework was presented to study technological regimes and their possible transformation as a result of feedbacks from their environment. In this chapter, a number of more specific conceptual tools will be added that are instrumental in understanding continuity and change in technological regimes and that are helpful for the data-gathering and the analysis of the case studies.
The first section of this chapter discusses the different types of actor roles that can be distinguished in technological regimes. Five ideal typical roles are distinguished that are useful for the analysis and characterization of particular regimes.
In the next section, four mechanisms of technological change are described. These mechanisms are important for understanding cumulative and coordinated technological development in technological regimes. These mechanisms do, however, not necessarily or in all circumstances result in cumulative and patterned technological development. They are also important for the dynamics of processes of transformation.
The final section of the chapter describes the four innovation patterns that are used as basis for the selection of the case studies. These innovation patterns are based on Pavitt (1984) but extend his analysis somewhat. The four innovation patterns differ with respect to the place in the triangle of technological development where innovations usually start and with respect to the actors that usually initiate innovation. In the R&D-dependent innovation pattern, innovations usually start with new technological promises based on new scientific and technical ideas developed in R&D laboratories and institutes. In the supplier-dependent innovation pattern, innovations usually start with new component parts developed by suppliers. In the user-driven innovation pattern, innovations will be based on functional requirements of users and in the mission-oriented pattern, they will be based on missions formulated by governmental actors.

2.1 Divisions of Labor and Roles in Technological Regimes

In technological regimes, there is a division of labor between actors and the institutionalization of particular activities in roles. Roles in a technological regime may be created deliberately but may also emerge as an unintended result of historical developments. It is not necessary that an overarching organization exists that 'organizes' the roles. Roles can inhere in shared interaction elements as technical models, promises and guiding principles.
Since divisions of labor and roles in technological regimes are historical outcomes, they may differ significantly from one technological regime to another. Nevertheless, certain activities with corresponding roles can be discerned, which apply to a large number of technological regimes. Such ideal typical roles are helpful for the analysis and characterization of particular technological regimes, even if their exact content and institutionalization will differ from technological regime to technological regime.
In this section, I will briefly describe five types of roles that exist in technological regimes: *designers* and *producers* of the artefacts that are typical for a technological regime, *researchers* doing R&D and scientific research, *suppliers* of component

parts, *regulators* formulating and enforcing rules with respect to the design, production and use of the artefact and *users* using the products and possibly articulating a desire for certain functions to be fulfilled. In addition to these actors, societal groups may impinge on the development of technology.

Designers and Producers

Designers design the artefacts that are typical of particular technological regimes and producers produce them. The actual design of artefacts usually takes place at commercial companies, engineering firms and governmental bodies. Engineers and marketing people working at these organizations will also play a major role in the translation of more or less articulated functions into design requirements and criteria, because this translation requires specialized knowledge and insight into what is technically feasible. The same organizations that design particular artefacts will often also produce them. In such cases, I will speak of the designer/producer of a technology.

Researchers

R&D activities and scientific and technological research can either be supportive for existing products or innovative. I will call the role associated with the carrying out of both kinds of R&D activities that of researcher. In most technological regimes, this role is carried out by several actors. Research activities take place at R&D departments of firms, at universities and engineering schools, at trade-association laboratories, research foundations, government bureaus, engineering firms, et cetera.

Suppliers

Many technical products consist of technical (sub)components produced by firms other than the designer/producer of the complete artefact. I call the role associated with the design and production of component parts that of supplier. Like researchers, suppliers may play a supportive as well as an innovative role in technological regimes. At the one extreme, suppliers produce exchangeable parts that can be used as black boxes by the designer/producers in the design of artefacts. In that - hypothetical - situation, designer/producers can simply 'plug in' the supplied part in the artefacts that they are designing and producing. They do not have to bother about interactions with other parts or consequences for the overall functioning of the artefact. The supplied part 'simply' fulfills its sub-function. At the other extreme, new parts require radical changes in other component parts and the overall structure of the artefact to be designed. This may ultimately lead to new artefacts, which are based on new technical models and hierarchies.

Suppliers may play an innovative role due to the R&D they do. Many innovations in paints, for example, derived from the development of new chemical substances by chemical suppliers.[1] It is, however, no necessity that supplier-induced innovations eventually derive from scientific developments. An interesting example is the zipper, which set in motion a range of innovations in clothing and coverings.[2] This 'device' did not derive from scientific research. Textile firms acquired this technology thanks to their suppliers.

Regulators

Regulators undertake a whole range of regulating, promotional and coordinating activities in technological regimes. The role of regulator may be taken up by such actors as governments, (semi)governmental agencies, standardization and certification institutes, professional societies and branch organizations. Typical for all these actors is that they are active at what Disco & Van der Meulen (1998) call the global level of a technological regime, *i.e.* the level at which the regime as a whole is shaped.

Regulators play an important role in the formulation of mandatory requirements for technical products, for example, with respect to the safety of products or the substances allowed to be used. Often, such standards or requirements are formulated and enforced by regulatory bodies that are specific for the relevant technological regimes. Think of the role of institutions like the (American) Federal Aviation Agency (FAA) with respect to aircraft design and use, and the (American) Atomic Energy Commission (AEC) with respect to the design and use of nuclear reactors. Both institutions also play a role with respect to the certification of designs. Certification refers to the process in which a regulatory body checks whether a design or a particular product fits certain obligatory requirements.

Regulatory bodies can also influence the formulation of requirements in more indirect ways. Governments can, for example, require certain procedures for the development of new technological products or the carrying out of technical projects. The obligation to carry out an Environmental Impact Statement (EIS) is an example. Also, the introduction of product liability influences how different kinds of artefacts are designed in technological regimes.

By acting on the global level of a technological regime, regulators are reflexively aware that something like a technological regime exists, even when they do not use this term. This awareness will motivate them to keep an eye on the long-term interests of the actors involved and the viability of a technological regime as a whole. Therefore, they will try to maintain the boundaries of the existing regime. Such boundary maintenance consists of two related processes: inside maintenance and outside maintenance.[3] Inside maintenance aims at keeping insiders in line, hence at keeping technological development cumulative and coordinated. Outsider maintenance aims at keeping outsiders out and feedbacks from the environment latent.[4]

The importance of inside and outside maintenance is often realized by actors within a technological regime. To achieve it, they may establish special organizations that are active at the global level of the regime. Examples of such organizations are professional societies and branch organizations. These organizations can be conceived as what Streeck & Schmitter (1985), among others, have called ‘private interest governments.’ This term refers to ‘the self-‘government’ of *categories of social actors* defined by a *collective self-regarding interest*.’[5] Such categories of social actors are, for example, engineers with the same professional background or firms in the same branch. Such actors may establish organizations to reach certain categorical goods that might not have been achieved otherwise. Categorical goods are goods that are in the common interest of a limited group of actors, here regime insiders. Coordinated and cumulative technological development and keeping feedbacks from the environment latent are examples of such categorical goods.

Users

Users use the products designed and produced in a technological regime. Sometimes, products will be used by chains of users. Some users use the technology to produce another good that is used by other users, et cetera. Technological regimes then are characterized by a number of, what Schwartz Cowan has called, consumption junctions.[6]

The specific role of users will differ from one technological regime to another. To capture this, I distinguish three types of users:

- *Anonymous consumers*. Anonymous consumers are anonymous to the firms designing the artefact. Usually, they are end users; the artefact is not used for the production of another economic good. Anonymous consumers are not directly involved in the articulation of functions.[7] They will 'only' play a role in the articulation of functions via market selection. Their involvement is merely reactive; users react to designed artefacts that are often based on assumptions made by marketing departments about the wishes of users. Such marketing departments may try to find out the wishes of users via marketing polls, user experiments or consumer organizations.

- *Professional users*.[a] Professional users are performance-sensitive users for whom the artefact is of crucial importance for the production of another economic good. So, a producer of electric circuits is a professional user of apparatus for electric circuit production, but not of pencils (for which, it is an anonymous consumer). Professional users will often have a direct role in the articulation of functions. Professional users may possess crucial knowledge and experience and, therefore, be involved in the translation of functions into more concrete functional requirements and in the actual design process, *i.e.* the translation of requirements into artefacts.

- *Government as client*. I am mainly interested in the government as principal or client of products seen as crucial for the execution of governmental tasks, and not in the government as user or consumer of consumer goods. The government as client may be seen as a special instance of professional users. A main difference is that the articulation of functions by the government is not so much dependent on the marketplace, but on (democratic) political decision-making. Typical examples are military technology and infrastructure (roads, bridges, railways). In such cases, governmental bodies formulate a mission, broadly defining the functions to be fulfilled and a set of boundary conditions, which the

a Here, the term 'professional' does not refer to the (learned) professions like medicine or engineering, but to the fact that users use the product as (crucial) part of their occupation and in order to produce another (economic) good.

designed technologies should respect. Such a mission may apply to particular projects or to an entire technological regime.

These different kinds of users will be involved in different ways in the articulation of functions and in design processes. One difference is that in the case of anonymous consumers and professional users, the articulation of functions takes place via the marketplace, while in the case of the government as client, bureaucratic and political decision-making is important. Another important difference is that anonymous consumers will, as a rule, merely react to proposals for functions (inherent in artefacts), while professional users and governments as client can actively propose new functions or a new mission. Moreover, such users may be directly involved in the design process. So, governments as client and professional users can play an innovative role in technological regimes by proposing new functions.

Societal Actors

Various societal actors such as banks, insurance companies and stockholders may impinge on the definition of the different elements in the triangle of technological development and, in particular, on the definition of design criteria and requirements. If such societal actors do so on a regular basis and according to a set of more or less stabilized rules, I will see them as regime insiders. Otherwise, they are outsiders that may become involved by making feedbacks from the environment of a technological regime manifest and, hence, initiating a process of transformation.

2.2 Mechanisms of Technological Change

In this section, I will discuss four mechanisms that are important for understanding technological change in technological regimes: 1) competition and market selection; 2) technical models and hierarchies (technology as rooted in the past); 3) promises and expectations (technology as rooted in the future) and 4) guiding principles.

The first mechanism particularly relates to interdependencies as they exist in technological regimes. The other three relate to elements in the upper part of the triangle of technological development (Chapter 1). As we will see, these elements contain rules to change elements in the lower part of the triangle of technological development. They, therefore, enable cumulative and coordinated technological development in technological regimes.

Competition and Market Selection

Competition is a type of interdependency that is of special importance for technological development. Many technical products are designed and produced in companies which compete on markets. Such companies are dependent on other companies through the market, which is an aggregation effect of the behavior of competing firms and customers.

Economists suggest that competition leads to innovation.[8] Competition stimulates firms to develop strategies to beat their competitor or to avoid a loss of market share.

The development of new products can be one strategy. This strategy is, however, not always the most attractive. Firms can also try to beat their competitors in other ways than by technical innovation, for example by price wars. Innovations often bring extra costs and introduce serious risks and uncertainties for the firm. Hence, it may be more attractive to wait for other companies to take the initiative in developing an innovation.[9] Nevertheless, if one company might successfully develop and introduce a new product, other companies, fearing a loss of market share, will follow and work on product and process innovation as well.
This mechanism can be found in any situation where competition among the actors producing a technology exists. Ferguson has described how a process of gradual and cumulative innovation was set in motion when an American blacksmith successfully changed the design of the existing European axe:

> *The distinctive American axe of the eighteenth and nineteenth century originated when a blacksmith modified the design of traditional European axes ... . The head was made heavier all over, and increasing the proportion of metal in the poll radically improved the balance of the axe for heavy chopping and for felling trees. The new style was further modified by other blacksmiths who heeded the suggestions and criticisms of experienced axemen*.[10]

After the initiative of one blacksmith, new axe forms were realized by actors such as blacksmiths and axemen on the basis of earlier interaction outcomes. In other words: the interaction outcomes were fed back to the system of interaction and led to new interactions and subsequently to new interaction outcomes. A process of accumulative innovation was set in motion.

Competition can lead to coordinated and cumulative technological development, and market selection is a dominant factor. Since not all artefacts produced by (commercial) firms will be equally successful, selection of successful technologies takes place. This selection can be the result of firms mimicking the successful products of their competitors. Selection can also be an aggregation effect and take place behind the backs of the actors involved. Some products are simply not sold, and companies producing less successful technical products may be forced out of business, go bankrupt or are taken over.
The selection of technical products is not an optimization process independent of historical circumstances; it is path-dependent. Sometimes, products are selected not because they perform better in the eyes of users but because they were adopted earlier and on a larger scale than competing products.[11] Users of computers may, for example, buy and use Windows 95 not because they consider this product intrinsically better than its competitors but because of the (expected) widespread use of Windows 95. Using the same software platform as other users has advantages in terms of compatibility if one is to exchange work. Using a widely used software platform has the advantage that other producers of software will make their products compatible to that software platform.

The exact reasons why a technological product becomes more attractive the more it is adopted may differ from case to case.[a] The overall effect is essentially the same. As Arthur has expressed it:

> *[I]f increasing returns to adoption are ... present, they determine the character of competition between technologies. If one technology gets ahead by good fortune, it gains an advantage. It can then attract further adopters who might otherwise have gone along with one of its rivals, with the result that the adoption market may 'tip' in its favor and may end dominated by it ... . Given other circumstances, of course, a different technology might have been favored early on, and it might have come to dominate the market.*[12]

The process of adoption then leads to a lock-in, 'in the sense that the left-behind technology would need to bridge a widening gap if it is to be chosen by adopters at all.'[13] This is also the case if the technology left behind would potentially - if adopted at the same scale - perform better in the eyes of customers or would introduce fewer harmful secondary effects than the 'winning' product. A lock-in occurs and does not favor the best technology.

Selection of technologies does not only take place ex post - after technical products have entered the market, but also ex ante. Firms anticipate the selection of technical products by the market, and/or they mimic the behavior of - what they consider successful - competitors.[14]
Ex ante selection of technologies does not necessarily take place in anticipation on market selection.[15] In fact, especially for new technologies, it is very hard - if not impossible - to know beforehand which technical products will eventually be successful. Since most firms cannot afford to develop all underlying technologies that can be possibly used in the design of technical products, they will concentrate on a limited number of underlying technologies. Among other things, their choice will be based on existing technological competencies, and on what seem promising new technologies.[16] This means that technology may be rooted in the past (existing competencies) as well as in the future (promises).

Technology Rooted in the Past; Technical Models and Hierarchies

Technological competencies of firms do not exist in isolation. They are related to forms of knowledge and design tools that are commonly used in technological

a Arthur (1988, 591) lists the following five sources of 'increased returns to adoption':
1) Learning by using: the more a technology is used the more is learned about it the more it is improved;
2) Network externalities: the more a technology is used by other users the larger the availability and variety of (related) products that come available and are adapted to the product used;
3) Scale economies in production;
4) Informational increasing returns: the more a technology is used the more it is known among users;
5) Technological interrelatedness.

regimes. To capture this sharing of cognitive resources, Disco, Rip & Van der Meulen (1992) elaborate on the role of so-called technical models and technical hierarchies in technological regimes. They trace the role of technical models and hierarchies historically and are able to show that technical models and hierarchies are important for the transition from, what they call, local technological regimes to global technological regimes. In the local situation, technical models and hierarchies exist more or less in isolation within a firm or a conglomerate of firms. They are developed ad hoc by individual designers or in local design teams. In the course of time, however, technical models and hierarchies became shared among larger ranges of actors. For technological models, Disco, Rip & Van der Meulen (1992) describe this general development as follows:

> *In the classic configuration of the 19th and early 20th centuries ... technical models generally started out as local and ad hoc constructions, and only later tended to become stabilized within the cosmopolitan culture as standard generators of design heuristics. The construction of technical models ... gradually became a distinct type of activity within the overall process of engineering design, i.e. ... gradually became the province of research specialists within a cosmopolitan division of technological labour.*[17]

With the sharing of technical models, technological regimes became more global in nature. Technical models enabled research activities - preeminently the construction and optimization of technical models - relatively independent from actual design processes. This meant that, for example, universities could concentrate on the (scientific) optimization of technical models without directly being involved in design processes. In this way, technical models enable the splitting up of design and research activities.[a] In this new situation, described as the cosmopolitization or globalization of technological regimes by Disco, Rip & Van der Meulen (1992), competencies of firms clearly do not exist in isolation.

While technical models enable the splitting up of design and research activities, technical hierarchies enable divisions of labor with respect to (sub)components of products. Disco, Rip & Van der Meulen (1992) give the following categorization of the technical hierarchy of technological products:

a Also important in this respect, is the establishment of the technical sciences in the course of the 18th and 19th century; these applied themselves to more general cognitive deliberations on technology and technological development (Sebestik, 1983; Disco, Rip & Van der Meulen, 1992). In the same period, special schools for engineers were established in various countries (*Ibid.*; Noble, 1977). Increasingly, generation of technological knowledge and the education of engineers became activities, which were also institutionally differentiated from design and development of technology. (Stankiewicz, 1992). Universities and engineering schools played a role in the development and dissemination of technical models, as did professional societies of engineers, most of which were established in the 19th and early 20th century.

- *components (e.g. materials, nuts and bolts, resistors and condensors, radio vacuum tubes) that do not "perform" by themselves, but have to be assembled to do their job;*
- *devices (e.g. a pump, a switching circuit, a sensor) that are assembled sufficiently to show their primary effect;*
- *functional artifacts (e.g. a machine, a bridge, a radio), that work by themselves;*
- *systems (a plant, an electricity network, radio broadcasting plus receivers plus organizations to produce radio programmes) that fulfil a sociotechnical function.*[18]

Production and design activities at these different levels can, to some extent, be organized and carried out independently of each other. Historically, the division in design labor often followed on the division in production labor.[19] According to Disco, Rip & Van der Meulen (1992), the latter tended to bring about the first:

> *Initially, one would imagine that both process equipment and components were ordered from more or less specialized producers on a one-time basis and according to customized and detailed specifications. In this phase, production is dispersed but the design process is not; for example, a manufacturer of linen also designs the power looms he wants to use. Clearly this is an unstable phase because expertise on loom building tends to accumulate at the loom manufactory and not at the textile plant; the former is not only intimately acquainted with the actual making of looms but also - as a recipient of detailed specifications and accounts of practical experiences - with the various local demands made on looms throughout the textile industry. As a repository of specialized knowledge and skills relating to looms, the loom manufacturer is in an increasingly favourable position to provide valuable technical and commercial advice to the textile plant, to become, in effect, co-designer of textile processing equipment. Ultimately, as larger markets began to solidify, the loom manufacturer's potential advantage can provide him with a virtual design monopoly; thenceforth industrial customers may purchase looms prêt à porter from trade catalogues.*[20]

Here, design activities are taken over by the supplier of process equipment. In other cases, suppliers began to design components independently from their clients who integrated these components into artefacts that they designed and produced.[21] In such cases, coordination could no longer rest on ad hoc formulated technical hierarchies. What was required was an inter-organizational splitting up of design activities according to a generally accepted technical hierarchy. For this, the interactions between the different (sub)components should by and large be understood. Then, design tasks at the lower hierarchical levels could be formulated, which were constrained by requirements deriving from the functioning, and the structure, of the artefact as a whole.[22] Formulation of such requirements, was only possible if the measures in which the properties of products were measured were somewhat standardized. As for technical models, this kind of standardization relied on prior

standardization in science, although new technologies sometimes required new measures and new measurement methods.[23]
Another kind of standardization that was important for divisions of labor along the lines of technical hierarchies was the development of industrial standards and norms. Industrial standardization made it possible for suppliers to develop products, and to do R&D, with a respect to generalized specifications without bothering too much about the wishes of individual customers. An advantage for the producers of complete artefacts was that components and devices offered by suppliers became interchangeable. Industries like the railways and the automobile industry began to strive for such inter-company standards and norms in the late 19th and early 20th century.[24] Later, also professional societies and especially established governmental offices for standards and norms began to work towards industry-wide norms and standards.[25]

Apart from the sketched divisions of labor between designer/producers and researchers (technical models) and between designer/producers and suppliers (technical hierarchy), technical models and hierarchies may enable more specific divisions of design labor. Van der Meulen (1992) has shown how technical models of propeller systems for ships enable cooperation among such heterogeneous actors like shipping companies, shipyards, consultants, mechanical designers, hydrodynamic designers, test stations and engineering scientists.[26] In such cases, the technical model allocates different roles to the different actors involved. Meanwhile, the technical model - to be effective - will build on already existing divisions of design labor and roles.
Once technical models and hierarchies are generally accepted in a technological regime, they also create interdependencies among actors. Engineers are not only dependent on existing technical models and hierarchies for the development of technical products, but also rely on them to communicate with, and to profit from other actors like scientific researchers, test laboratories and suppliers. Shared technical models and hierarchies thus coordinate the behavior of the involved actors and result in cumulative design efforts.
Technical models also help to explain how exclusion of certain actors from design activities takes place. Disco, Rip & Van der Meulen (1992) relate this role of technical models to the establishment of engineering professions since the 19th century:

> *Unanimity and uniformity of design protocols (and especially of technical models) was a central value for the newly self-conscious engineering professions. In the first place, their demonstrative commitment to scientific scrutiny legitimated their claim to unique expertise in the optimization of design practices ... In the second place, uniformity of technical models, insofar as it also entailed the standardization of symbolic representations and algorithms, facilitated communication among professional engineers (e.g. electrical circuit diagrams or stress calculations for bridges produced in one location could be routinely "read" and critized by professional colleagues elsewhere). As uniformity in technical modeling thus cemented*

professional solidarities, it also set up significant symbolic and linguistic barriers against competition from non-professional practitioners.[27]

Technical models will not only constrain the range of people involved in technological development, but also the range of technical options. Both technical models and hierarchies define what is technologically possible at the time and suggest heuristics and trajectories for further progress. They contain rules for the gradual creation of new alignments between technical configurations and functions and the development of new artefacts. So, technical models and technical hierarchies enable coordinated and cumulative design efforts, leading to patterns of technological development in which technical configurations and functions are gradually changed on the basis of experience.

Technology Rooted in the Future: Promises and Expectations

While technical models and hierarchies are supportive for the design of existing classes of artefacts, scientific and technological research can also provide ideas and opportunities for new classes of artefacts, giving rise to new technological domains and regimes (like nuclear energy and biotechnology), or to innovations in existing technological regimes that depart from existing technical model and hierarchies. This innovating role of research was first institutionalized with the establishment of industrial laboratories in the electronic and the chemical industry in the late 19th and early 20th century, and has since led to a myriad of research activities sponsored by commercial firms and governments.[28] Especially since the Second World War, technological research and the generation of technological knowledge are seen as a strategic resource, not only in the competition between firms but also in the competition between countries for prosperity, employment and prestige.[29] As a result, governments have become deeply involved in the organization and funding of R&D activities in some technical sectors.[30]

A specific way in which scientific and technological research can lead to innovation is by the creation of what Constant has called a presumptive anomaly.[31] According to Constant, a presumptive anomaly arises if an old technology still functions, 'indeed still may offer substantial development potential, but science suggests that the leading edge of future practice will have a radically different foundation.'[32] A typical example of innovation by presumptive anomaly given by Constant is the turbojet revolution.[33] The turbojet is a kind of aero-engine, which largely replaced the existing aero-engines - a combination of propellers with piston engines - between the forties and sixties.[34] The turbojet was initially developed by a handful of engineers and scientists. Given the earlier advances in streamlining of the aircraft, they presumed that the propeller would become the limiting element if future increases in aircraft speed were to be achieved. According to Constant, they derived this insight from aerodynamic science:

The presumptive anomaly ... derived solely and directly from advances in aerodynamics and comprised the conjunction of radical assumptions about internal combustion gas turbine component efficiencies. Those men saw

> *what mature subsonic aerodynamics and the first insights of supersonic aerodynamics implied: that but for the propeller the new stressed-skin, well-streamlined airframes were perfectly capable of flying at near-sonic speeds*.[35]

This presumptive anomaly made a small number of people focus their attention on new technological options like the turbojet, while the existing technology (piston engines with propellers) was not yet malfunctioning or without development potential.[36] When they eventually succeeded in developing this new technological option and aligning it to new functions like high-altitude flight and flight at higher speeds, the technological promise was turned into a successful innovation.
As this example shows, presumptive anomalies - and scientific and technological insights in general - may focus the attention of at least some scientists and engineers on a new technological promise or a new generation of technical products, even when the existing technology still functions.[37]

To understand how innovation, departing from existing technical models and hierarchies, can take place, while technological development stays cumulative and coordinated, we have to focus on the role of expectations and promises in technological development. This role has been analyzed by Harro van Lente.[38] He describes how technological development is not only rooted in the past, as with technical models and hierarchies, but also in expected future states. This is important to understand how new technical configurations or functions are proposed and realized in a technological regime without having an enduring disaligning effect. If such new technical configurations or functions are based on expectations, which are shared from the outset, coordinated and cumulative efforts with respect to a strived-for new alignment of technical configurations and functions already take place, even before the actual artefact has been developed.[39]
Initially, expectations or promises of new technological opportunities will start as constructions (interaction outcomes) of a limited number of actors. They may be based on a presumptive anomaly or on new component parts developed by suppliers. Through diverse communication channels, such expectations become more widely available to the actors in a technological regime, and are accepted as obvious. In this way, they become available as a resource. Actors may then begin to use such stabilized expectations to legitimize their behavior, to mobilize other actors and funds for certain purposes or to reduce the uncertainty that is inherent in technological development.[40] Especially competing firms, which are uncertain about the potential of new technologies and the behavior of rival firms or clients, use accepted expectations as an uncertainty reducing device.
As expectations become shared among a larger number of actors, they begin to guide the actions of these actors. Expectations may, for example, allocate roles to particular actors: they make different actors responsible for tasks to be carried out to make the expectation come true.[41] If such role allocations are accepted by the actors involved, their behavior will be coordinated. The promises inherent in the expectations are then also translated into more concrete requirements, to be used in the design of the new technology.[42] Promises and expectations thus contain rules for

the redefinition of elements such as requirements and specifications that are at a lower level in the triangle of technological development. In this way, promises and expectations help to maintain coordinated and cumulative forms of technological development.

A dynamics of promises and expectations can also lead to successive generations of technical products. If the idea of subsequent generations of technical products is commonly shared in an existing technological regime, it may well become a self-fulfilling prophecy. An example is Moore's Law.[43] This 'law' predicts that the complexity of chips, expressed in the number of 'gates', will double every one and a half year. The law holds not because it represents some deeper reality of chip development but because the actors involved believe in it. One reason for the firms and governments involved to do so is that their competitors do; the situation has the structure of a prisoner's dilemma. By acting on the basis of Moore's Law, the actors involved make the law come true; it is a self-fulfilling prophecy.

In many technological regimes, innovations will be rooted both in existing technical models and hierarchies, and in promises or expectations about next-generation products. The establishment of a new generation of technical products does not necessarily make the older generation obsolete. Older generations may coexist alongside new generations, especially in market niches. Moreover, in the redesign of existing products some next-generation features may be incorporated without radically changing the overall design.

Apart from promises and expectations specific to particular technological regimes, more general promises and expectations about technology are important, up to the general promise of 'technological progress' shared by many in our society. As Van Lente says: 'Support for concrete technological developments can be mobilized and legitimized by presenting them as instances of 'technological progress'.'[44] He argues that this general promise creates a cultural space for specific technological promises and expectations:

> *'Space', in this respect denotes an openness, a receptivity, as well as a location, a domain. In its first meaning it captures the situation that our culture lends a ready ear to proposals of technological novelty, which make it relatively easy to have such proposals accepted. In its second meaning, it refers to the culturally accepted and culturally anchored domain for technologists to work out promising technologies*.[45]

The fact that 'technological progress' is generally accepted as a legitimation makes it easier for engineers and scientists in particular technological regimes to strive for innovation.

The inclination toward technical innovation should, however, not be interpreted as implying that all instances of technical innovation are accepted easily in technological regimes. The existence of technological regimes implies that innovation follows particular patterns. Some promises and expectations will be accepted more readily in a technological regime than others, depending on the specific characteristics of the existing technological regime.

Guiding Principles

The concept of guiding principle was originally developed by Wim Smit in relation to military technology. He defines a guiding principle

> *first, as an inter-organisational concept, that plays a role in the interactions between the various organizations in the military technology network, and, second as an interface between military doctrines or strategies ... and the concrete shaping of weapon systems.'*[46]

A guiding principle is used as a legitimating principle by the various actors involved in technological development. It guides and restricts their (inter)actions by relating them, explicitly or implicitly, to general strategies, doctrines or values.[47] An example of a guiding principle is the striving for efficiency in the design of battery cages. Efficiency became a shared value in the research, design and use of battery cages in the fifties and sixties (for more details, see Chapter 5). This implies that actors will normally not undertake actions that cannot be justified in terms of this guiding principle. That actors will not do so is due to the legitimating power of the guiding principle.

For actors that interact with each other on a regular basis, establishing a minimal amount of mutual trust and cooperation is important. This trust and cooperation will often be tacit. Corporations, for example, depend on the trust and cooperation of their customers but do not need the explicit consent of their customers for their actions. The corporation should be able to legitimize its behavior when called upon. If it regularly fails to do so, customers will ultimately lose trust and give up their (tacit) cooperation, *i.e.* they will stop buying the products of the company.

Thus, actors that regularly interact with each other legitimize their behavior vis-à-vis each other.[48] A guiding principle functions as a generally accepted rhetorical resource to legitimate one's behavior and as a generally accepted touchstone to judge the behavior of others. Actors will therefore normally not undertake actions that cannot be defended in terms of the guiding principle.

Guiding principles contain rules for the (re)definition of elements at the lower levels in the triangle of technological development. They are translated into such elements as design criteria and requirements and specifications. Such lower level elements in turn contain rules that guide the day-to-day practices of the relevant actors. Therefore, guiding principles enable innovation and, meanwhile, constrain innovation to patterns that fit the principle. As a result, technological development is coordinated and cumulative.

Guiding principles also help to keep feedbacks from the environment latent. They do so because they help to convince outsiders of the legitimacy of the existing technological regime and its outcomes. If a technological regime is generally seen as legitimate, outsiders will have less motivation and opportunity to intervene and to make feedbacks from the environment manifest.

2.3 Patterns of Innovation

In technological regimes, the alignment between technical configurations and functions is often a dynamic process. New alignments between technical configurations and functions are created continually, for example as a result of the sharing of promises, and their translation into requirements and new artefacts. Although technological change takes place continually in most technological regimes, often it is cumulative and patterned. As we saw in the preceding section, elements at the higher levels of the triangle of technological development contain rules to change elements at the lower levels. As a result, some elements (rules) of technological regimes change while others remain the same. Which elements keep stable and what patterns may be discerned depends on the specific history of the regime under study. Nevertheless, some general patterns can be distinguished with respect to the way in which central elements of technological regimes change. I will call these patterns 'innovation patterns' and distinguish four of them: the R&D-dependent innovation pattern; the supplier-dependent innovation pattern, the user-driven innovation pattern and the mission-oriented innovation pattern. These different innovation patterns are characterized by different interdependencies and role-relations between the actors involved. Therefore, they enable and constrain the actions of individual actors differently and individual actions add up to collective effects in different ways. The additional and more speculative point is that the way in which different innovation patterns enable and constrain processes of transformation are also different. This is more speculative because transformation occurs through feedback from the environment, with inputs which are not shaped by the existing innovation pattern.

The four innovation patterns that I distinguish are primarily based on Pavitt (1984) who distinguished different types of innovating firms on the basis of an analysis of a large number of innovations in the UK and a categorization of innovating firms along three variables (user needs, sources of technology, means of appropriating benefits). I will modify and extend Pavitt's analysis in three ways. First, I will add an extra category of firms at which Pavitt already hinted but which was not included in his sample of innovations, because he focuses on innovations in the private sector. Second, I will define the innovation patterns in terms of relations between actors in a technological regime instead of in terms of characteristics of individual firms, as Pavitt does. These relations make up the structure of the interaction system in which a technological regime is embedded. Third, I will relate the way in which technical innovation is initiated in each of the four patterns to the triangle of technological development.

Pavitt's Categorization of Innovating Firms

Pavitt distinguished four types of innovating firms. I will add a fifth type, at which Pavitt already hinted.

- The first type of companies is described by Pavitt as *supplier-dominated firms*. These 'can be found mainly in traditional sectors of manufacturing, and in agriculture, housebuilding, informal household production, and many professional, financial and commercial services. They are generally small, and their in-house R&D and engineering capabilities are weak. They appropriate less on the basis of a technological advantage, than of professional skills, aesthetic design, trademarks and advertising.'[49] The users of these companies are, according to Pavitt, price-sensitive. In my terminology, these are anonymous consumers. Supplier-dominated firms do not primarily aim at product innovation. Instead, they try to obtain relative advantage vis-à-vis competitors by low-technological diversification and marketing. Insofar innovations take place, they mostly 'come from suppliers of equipment and materials, although in some cases large customers and government-financed research and extension services also make a contribution.'[50]

- The second type of companies Pavitt distinguishes is *scale-intensive firms*. These employ large-scale fabrication and assembly production.[51] Like supplier-dominated firms, their customers are price-sensitive and, presumably, anonymous consumers. These companies try to reach relative advantage vis-à-vis their competitors by exploitation of economies of scale (dynamic learning economies), process secrecy and know-how, technical lags and patents. Scale intensive firms are usually large and produce a relative large amount of their own process technology.[52] For both process and product innovation, suppliers will - apart from R&D within and outside the company - be a main source of innovation.[53] Examples of scale-intensive firms are producers of consumer durables and transport equipment and metal manufacturers.[54]

- The third type of companies is *specialized suppliers*. In contrast to the second category, these are mainly small firms. Their strength is their knowledge of, and often cooperation with their users, combined with design know-how. Innovations often derive from direct contacts with professional users, who usually posses relevant knowledge and may even be directly involved in the design process. Between specialized suppliers and their (large) users, often a close and complementary relationship will exist: 'Large users provide operating experience, testing facilities and even design and development resources for specialised equipment suppliers. Such suppliers in turn provide their large customers with specialised knowledge and experience as a result of designing and building equipment for a variety of users, often spread across a number of industries.'[55] Examples of specialized suppliers are the producers of medical apparatus and scientific instrumentation. Also engineering firms can be categorized as specialized suppliers.

- The fourth and final category of firms distinguished by Pavitt is *science-based firms*. Such companies '... are to be found in the chemical and electronic/electrical sectors. In both of them, the main sources of technology are the R&D activities of firms in the sectors, based on the rapid development of the underlying sciences in the universities and elsewhere... As Freeman et al. ... have shown, the development of successive waves of products has depended on the prior development of the relevant basic science.'[56] Science-based firms are usually large firms, like, for example, multinationals. They try to reach relative advantage vis-à-vis their competitors by means of R&D know-how. Also, process secrecy and know-how, patents and dynamic learning economies are important means for appropriating benefits. Technological innovation may derive not only from in-house R&D, but also from public research and R&D done by (semi)governmental agencies and universities.

- At the end of his article 'Sectoral patterns of technical change,' Pavitt suggests that a fifth category of firms 'should be added to cover purchases by government and utilities of expensive capital goods related to defense, energy, communications and transport.'[57] I will call such companies *common good producers*. Typical for such companies or government agencies is that they produce for the government as client or for a small number of (semi) governmental agencies. Contacts between the principal and the designer/producers will often be direct. Individual orders will be relatively

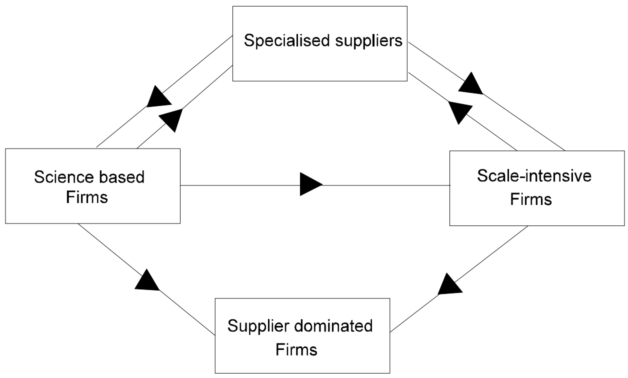


Figure 2.1 *Main Technological Linkages Between Different Categories of Firms. Reproduced from Pavitt (1984, 364).*

important and products will often be tailor-made.[58]

Pavitt also analyzed the main technological linkages as they exist between different innovating firms (Figure 2.1). This figure may be interpreted as representing the major supplier-customer relations and directions, in which technology is transferred. It should be realized that technology may also be embodied in a device or (sub)component. A chemical company delivering a new chemical substance with new properties to a paint company supplies not only a product but also a new technology; often, the chemical company will also supply information on the substance, directions for use or recipes for paint.[59] In other cases, products may be supplied while no (embodied) technology is transferred. Such customer-supplier relationships are not grasped by Figure 2.1.

Table 2.1 *Construction of the Four (Ideal Typical) Innovation Patterns on the Basis of Pavitt (1984)*

Type of innovating firm (Pavitt, 1984)	Role of suppliers	Role of researchers	Type/role of users	Role of regulators	Innovation pattern
Supplier-dominated	Innovative	Supportive	Anonymous consumers	Passive	Supplier-dependent
Scale-intensive	Innovative	Supportive	Anonymous consumers	Passive	Supplier-dependent
Specialized suppliers	Supportive	Supportive	Professional users (active role in innovation)	Passive	User-driven
Common good producers	Supportive	Supportive	Government as client (active role in innovation)		Mission-oriented
Science-based	Supportive	Innovative	Mixed	Passive	R&D-dependent

Four Innovation Patterns

Pavitt's analytical and empirical distinctions can be extended by relating them to the conceptual framework developed in Chapter 1. Pavitt defines the different types of innovating firms mainly in terms of individual characteristics of firms. These individual characteristics, however, reflect interdependencies and role-relations as they exist in technological regimes, in which the designer/producer is only one of the five actor roles. Pavitt is aware of the existence of interdependencies and role-relations; in fact, he uses them in his analysis. His presentation, however, emphasizes the individual characteristics of innovating firms.

Because relations between actors implicitly play a role in Pavitt's analysis, extending his analysis by reinterpreting it in terms of structures of technological regimes is not difficult. If we map the role of the other four types of actors in innovation, the supplier-dominated and scale-intensive pattern turn out to be similar (Table 2.1). So, we can reduce the five types of innovating firms to four ideal-typical innovation patterns: the supplier-dependent innovation pattern, the user-driven innovation pattern, the mission-oriented innovation pattern and the R&D-dependent innovation pattern. These patterns differ with respect to the actors that are the prime drivers of innovation. Since these different actors impinge on different elements of the triangle of technological development, innovations will also start in different ways and according to different mechanisms in the four patterns. In the supplier-dependent innovation pattern, innovations will usually start with new component parts; in the user-driven pattern, they will start with functional requirements of users; in the mission-oriented pattern with missions formulated by mission actors (the government as client) and in the R&D-dependent pattern they will start with technological promises or presumptive anomalies based on technological and scientific insights. Below, the four patterns are described in more detail.

Supplier-dependent Innovation Pattern

In a supplier-dependent innovation pattern, innovations originate within the supplying firms and not primarily at the designer/producer. Finally, such innovations may rest on R&D and advances in science. However, they are merely picked up by suppliers and reach the designer/producer in an embodied form, *i.e.* as new components and/or devices. So, in this pattern, suppliers play not only a supportive, but also an innovative role.

A supplier-dependent innovation pattern implies a division of design labor in which suppliers will do relatively much (innovative) R&D compared with the designers and producers of the entire artefact. One would expect such a division of design and R&D labor especially between science-based firms as suppliers and supplier-dominated firms as designer/producers. The first are usually large, committed to R&D and they develop long-term strategies. The latter are relatively small, depend for (product) innovation on suppliers and compete with each other on nontechnical features.

A comparable division of labor exists between science-based and scale-intensive firms. The latter will, in general, be larger than supplier-dominated firms and compete on (some) technical features. Further, economies of scale will be especially important for such firms. This also means that they, more than supplier-dominated firms, will develop long-term strategies with respect to production and product design. Nevertheless, they will depend on their suppliers for some, more radical, product innovations.

User-driven innovation pattern

In case of the user-driven innovation pattern, innovations derive from new functional requirements posed by users. In this pattern, users play an innovative role and direct contacts between the designer/producers of a technology and users exist. The (usual) division of labor between users and designer/producers may even be partially abolished. Typical designer/producers and users between which such a relation exists are specialized suppliers and professional users. The first appropriate benefits on the basis of design know-how, patents and knowledge of users. The second are performance-sensitive because the carrying out of their professional activities depends on the technology they use.

Innovation will be incremental and depend on the evolving practice of the users that may result in the formulation of new functional requirements. Knowledge generation for such (incremental) innovation, and the development of new technical configurations will primarily take place by the specialized suppliers and the professional users themselves. In the case of more radical innovations, researchers and suppliers will play a role too. This role will, however, be supportive rather than innovative, *i.e.* researchers and/or suppliers will undertake R&D and develop component parts mainly in response to functional requirements of users.

Mission-oriented innovation pattern

In a mission-oriented innovation pattern, innovations derive from a mission formulated by a powerful actor acting as principal for the artefacts designed. Such a mission defines the functions to be fulfilled by a technology and a set of boundaries conditions that should be respected by the designed technology. Missions define a framework within which innovations are accomplished.

Missions can be formulated with respect to specific projects and/or with respect to the regime as a whole. Both types of missions will usually be formulated by the government as client or, more precisely, by different governmental actors, such as governmental agencies and ministries. One governmental actor may act as principal for all projects. Different governmental actors may also formulate missions for specific projects.

In a mission-oriented innovation pattern, the designer/producers will usually be common good producers. Such common good producers may also themselves be governmental agencies. If they are part of the same agency as the government as client, the innovation pattern will be more outspoken mission-oriented because, then, the design of the technology will be guided by the existing mission in a more direct sense. Such a situation, for example, exists in the Dutch infrastructure sector. In this sector, governmental agencies - preeminently Rijkswaterstaat - act as client/principal, designer, researcher and regulator.[60] R&D and design activities, to an important extent, take place within the same organization that formulates the mission for the technological regime. The mission can be upheld via organizational (hierarchical) lines.

Table 2.2 *Characteristics of the Four (Ideal Typical) Innovation Patterns*

	Type of innovation firm	Type of user	Actors involved in innovation	Typical source/mechanism of innovation	Typical sectors
Supplier-dependent innovation pattern	Supplier-dominated Scale-intensive	Anonymous consumers	*Suppliers* (Researchers) Innovating firms	New (component) *parts*	Housing Traditional manufacture
User-driven innovation pattern	Specialized suppliers (Engineering firms)	Professional users	*Users* (Researchers) Innovating firms	*Functional requirements* of users	Machinery Instruments
Mission-oriented innovation pattern	Common good producers	Government as client	*Governmental actors* (Researchers) Innovating firms	*Mission(s)*	Infrastructure
R&D-dependent innovation pattern	Science-based	Mixed	*Researchers* Innovating firms	*Technological promises* (presumptive anomaly)	Electronics Chemicals

R&D-dependent Innovation Pattern

In an R&D-dependent innovation pattern, new alignments between technical configurations and functions come in successive generations of technical products. Innovation is based on ideas or conceptions for new technical configurations originating in R&D and the (underlying) sciences. Such ideas or conceptions may, for example, amount to a presumptive anomaly, *i.e.* the conviction that existing technical configurations might not be quite satisfactorily in the future, given what is, or might be, technologically possible. This may lead to promises of new artefacts, which presumably do a better job than the existing still functioning technology. Typical for an R&D-dependent innovation pattern is that promises initially apply to new technical configurations that are not yet realized. As such promises become shared, they begin to guide the actions of the involved actors and result in the development of new technical configurations. To achieve a successful innovation, these new technical configurations also have to be aligned to existing or new functions.

One expects an R&D-dependent innovation pattern especially in technological regimes, in which the designer/producers are science-based firms. Here, innovations are based on in-house R&D, sectoral research and public science. Patents and R&D know-how are important means for appropriating benefits for science-based firms. This will provide an incentive for such firms to develop and apply new technological and scientific insights.

The characteristics of the four innovation patterns are summarized in Table 2.2. In Chapter 3, this table will be used to check whether the cases are representative for the innovation pattern for which they were selected.

Notes To Chapter 2

1 For more details, see Appendix 3 and Chapter 4.

2 Disco, Rip & Van der Meulen (1992, 486).

3 Albert de la Bruhèze (1992).

4 An example of active outside maintenance is the (state) licensing system for engineers in the USA. In this country, only engineers with a license may practice their profession. (Exemptions may be made for particular categories of engineers like those working in industry, the so-called industrial exemption). According to Schaub & Pavlovic (1983, 508), '[a] license is granted under most state laws after a specified period of recognized engineering education (usually a four-year degree program in engineering), a period of experience under the direction of a registered engineer (typically, an additional four years), and rigorous examination that is most commonly of two days duration. In addition, the candidate must be of good moral character, present letters of recommendation, and may be subject to oral examination.'

5 Streeck & Schmitter (1985, 17).

6 Schwartz Cowan (1987).

7 Even if users are not actively involved in the formulation of functions - and requirements - the often implicit ideas of engineers about what users want, so-called *user representations*, will play a role in the design process (Akrich 1995).

8 Miller & Sawers have, for example, remarked about aircraft development: 'Competition stimulates innovation; this is the clearest lesson that one can draw from the history of the aircraft industry' (1968, 265). Clarke notes '[g]iven alternative design concepts and competition

among rival producers, uncertainty about technology and customer preferences leads to a diversity of technology in the products vying for customer acceptance' (1985, 238).

9 The two strategies that can be followed by firms in this respect are described by Hayward as follows: '... two broad approaches to the management of technological innovation [exist]. The first favors a gradual evolution of relevant technology, perhaps across a broad basis of related areas. This tend to favour the established manufacturer who has perhaps already written-off the high costs of developing an existing technology. But the nature of technological change might also bring a sudden, revolutionary and unpredictable lurch in the state-of-the-art, which could support a second, but high risk strategy, aimed at exploiting the new technology in a single bold move. This could render the competition's products obsolete overnight; but is fraught with greater technological and financial uncertainty. It may be an advantage to be first in the market, but equally, it may be better to 'second strike' the opposition, and to benefit from any lessons which have been painfully learnt by a pioneer. This ... represents one of the classic dilemmas of civil aerospace development (Hayward, 1986, 5). Although Hayward makes his observations with respect to aircraft design, the sketched dilemma in principle seems to apply to all technological innovations.

10 Ferguson (1992, 3-4).

11 Arthur (1988).

12 Arthur (1988, 591). Reference left out.

13 Arthur (1988, 593).

14 *Cf.* Östlund & Larsson (1991). Moreover, institutional linkages will evolve between actors active in the generation of technical products and actors who select among these products (users); marketing departments are an example (Van den Belt & Rip, 1987; Rip, 1992; Schot, 1992).

15 Dosi (1982).

16 *Cf.* Stoelhorst (1997).

17 Disco, Rip & Van der Meulen (1992, 477).

18 *Ibid.*, 485.

19 *Ibid.*.

20 *Ibid.*, 471.

21 For a concrete example of this process, see Van den Belt & Rip (1987).

22 Vincenti (1992).

23 *Cf.* Constant (1980, 228-229).

24 Noble (1977, 69-83).

25 Noble (1977).

26 Van der Meulen (1992, 122-130).

27 Disco, Rip & Van der Meulen (1992, 480).

28 See Noble (1977); Dennis (1987). Noble distinguishes three overlapping phases in the organization of science for industry in the USA: 'The first involved the establishment of organized research laboratories within the industrial cooperation, as integral parts of the enterprise. The second concerned the active support of, and cooperation with, research agencies outside of the corporations ... . The third saw the national coordination of these myriad research activities, primarily trough the National Research Council, in support of corporate industry. The first two developments began roughly around the turn of the century; the third surfaced during World War I.' (Noble, 1977, 112).

29 See, for example, Rip, Smit & Van der Meer (1990, 8-11).

30 An example is the aircraft industry, especially in Europe. See, for example, Todd & Simpson (1986).

31 Constant (1980 and 1987).

32 Constant (1987, 225).

33 Constant (1980).

34 Piston engines with propellers are still used for certain applications.

35 Constant (1980, 178). Note that this does not mean that the existing airframes were able to fly at near-sonic speeds. It only implies that, but for the propeller, the new aircraft in principle was able to fly at near-sonic speeds. Thus, Constant does not refer to a practical limitation - then the existing airframe probably was also limiting - but to a theoretical or principle limitation.

36 The development of the turbojet did not take place in the wake of an obsolete or stagnant technology. In fact: 'Measured on any plausible dimension - gross power output, power per pound or per cubic inch displacement, specific fuel consumption, altitude or speed attained, or total number in service - development of the aircraft piston engine achieved stunning and rarely paralleled technological success between 1910 and 1945' (Constant, 1980, 117).

37 Note that the sense of anomaly merely derives from theoretical deliberations and not from practical experience; hence, the term *presumptive* anomaly.

38 Van Lente (1993).

39 Of course, this in itself is no guarantee that the product will also be a success. The product may turn out to be technically impossible or may eventually not be accepted by users.

40 Van Lente (1993, 187).

41 *Ibid.*, 191-195.

42 *Ibid.*, 195-201.

43 *Ibid.*, 87.

44 *Ibid.*, 172.

45 *Ibid.*, 173.

46 Smit (1993, 402).

47 Enserink (1993); Van de Poel (1998).

48 The idea that actors should in principle be able to give justifications of their behavior goes back to Max Weber. For more details and an application to technological regimes, see Van de Poel & Disco (1996, 120ff). See also Strauss (1982) and Snellen (1983).

49 Pavitt (1984, 356). In particular circumstances, *i.e.* if economies of scale are attractive, supplier-dominated firms may be large firms. An example are textile firms (Dosi, 1988, 232).

50 Pavitt (1984, 356); emphasis added.

51 *Ibid.*, 358.

52 Dosi (1988, 232).

53 Pavitt (1984, 354).

54 Pavitt (1984, 554) and Dosi (1988, 232).

55 Pavitt (1984, 359).

56 *Ibid.*, 362; The reference is toward C. Freeman, J. Clark & L. Soete, *Unemployment and Technical Innovation: A study of Long Waves and Economic Development* (Frances Pinter, London, 1982).

57 Pavitt (1984, 370).

58 *Cf.* Mischgofsky (1991) who describes the industrial structure, innovations and the government's role in the infrastructure sector (*grond-, water- en wegenbouwsektor*) in the Netherlands.

59 *Cf.* Appendix 3 and Chapter 3.

60 Mischgofsky (1991).

Technological regimes are characterized by accepted ways of designing and further developing a technology (technical closure) and by accepted rules about who is in what way to contribute to the design and further development of a technology (social closure). Technical closure does not mean that the central elements of technological regimes - as depicted in the triangle of technological development (Chapter 1) - do not change. It means that some of these elements remain stable, while others change gradually and in a patterned way. Which elements remain the same and which change is historically contingent and will differ from technological regime to technological regime.

Cumulative and patterned technological change, as it takes place in an existing technological regime, is enabled and constrained by the innovation pattern of that regime. This innovation pattern defines the structure, the interdependencies and role-relations, of the interaction system in which the technological regime is embedded. It enables and constrains actions and interactions, including innovations. Four innovation patterns were distinguished. In these different innovation patterns, innovations are initiated by different actors and in different ways.

Technological regimes are transformed if feedbacks from their environment become manifest. During processes of transformation, elements of technological regimes that have remained the same for years may begin to change. Other elements that have changed over the years along a particular pattern may begin to change along new patterns or trajectories. These changes in the central elements of technological regimes will also result in changing alignments between technical configurations and functions. New artefacts embodying the new alignment between technical configurations and functions will be developed.

The development of technical alternatives during processes of transformation will presumably be enabled and constrained by the innovation pattern of the prior existing technological regime. This innovation pattern defines the structure of the situation in which actors have to act and in which particular technical alternatives are developed and possibly accepted. Technological regimes with a different initial innovation pattern will therefore presumably enable and constrain processes of transformation in different ways.

To study empirically whether different innovation patterns enable and constrain processes of transformation in different ways and to trace what these specific ways are, a multiple case study consisting of eight case studies of processes of transformation was carried out. These cases were selected as to represent, in pairs, the four innovation patterns (Table 3.1). That is to say: the innovation pattern of the prior existing technological regime had to match, by and large, the ideal typical innovation pattern for which the case was selected.

In this chapter, the selection of the cases and the gathering of data for the cases will be explained. Further, it will be checked whether the selected cases represent the innovation pattern for which they were selected. This is done by comparing empirically found characteristics of the studied technological regimes and of several past innovations in those regimes with the characteristics that would be expected from Table 2.2. As we will see, the selected cases largely represented the innovation patterns for which they were selected.

3.1 Case Selection and Data Gathering

The eight case studies of processes of transformation carried out were selected from a list of twenty, which was the result of an exploration of possible cases (Appendix 1). The following criteria have been used to select eight cases:

1) There had to be an existing technological regime. Technological regimes can be distinguished at different hierarchical levels: systems, artefacts, devices and components (*cf.* the discussion of technical hierarchy in Chapter 2). The choice was made to select technological regimes at the level of artefacts;

Table 3.1 *Case Studies Carried Out*

Existing innovation pattern	Cases
Supplier-dependent innovation pattern	*Household refrigerators*: The transformation toward refrigerators with environmentally sustainable coolants
	Paints: The transformation toward more environmentally sustainable paints
User-driven innovation pattern	*Chicken husbandry systems*: The transformation toward more ‘humane’, ‘animal benign’ chicken husbandry systems
	Sewage treatment plants: The transformation toward a larger role for biotechnology in the design of sewage plants
Mission-oriented innovation pattern	*Coastal barriers*: The transformation toward the incorporation of ecological design criteria
	Waterside bank constructions: The transformation toward ‘natural’ banks and the incorporation of ecological design criteria
R&D-dependent innovation pattern	*Aero-engines*: The transformation toward more ‘silent’ aero-engines
	Nuclear reactors: The transformation toward ‘inherently safe’ nuclear reactors

2) A process of transformation had to be initiated because outsiders succeeded in making feedbacks from the environment manifest;

3) Data on the case had to be available (*i.e.* not confidential, etc.);

4) As far as possible the general social and historical background against which the processes of transformation took place had to be similar. In practice, this meant that I have selected cases in which processes of transformation took place in the period between approximately 1960 and 1990. Further, the case studies were often located in the Netherlands. As we will see, this focus was not feasible in all cases.

5) Of each (initial) innovation pattern, two cases were selected. This was done by a *prima facie* assessment of the existing innovation pattern in the technological regime that was central in a potential case. Later, this prima facie judgement was checked by a method known as *pattern matching* (see Section 3.2).

The first two criteria follow from my conceptualization of technological regimes and processes of transformation in Chapter 1 and 2. I chose to study technological regimes at the level of artefacts to reduce the influence of the background variable 'level of technical hierarchy' on my outcomes. For similar reasons, the fourth criterion was added. The fifth criterion directly follows from my research design as explained in Chapter 1.

The case studies started with mapping existing technological regimes, especially the innovation patterns characteristic of those regimes. This was done with the conceptual tools developed in Chapter 2. The relevant actors, and their role in the technological regime, were mapped. Secondary literature on past innovations was studied to check whether such innovations fitted the (presumed) innovation pattern of the regime. The elements of the triangle of technological development were mapped as far as was necessary to study the process of transformation.
The mapping of the existing technological regime and its characteristic innovation pattern was restricted, as much as possible, to the Dutch situation. Such a restricted regime analysis is acceptable because often there exists something like a Dutch regime, discernibly different from technological regimes of the same type of artefacts in other countries. In three of the eight cases the analysis of the technological regime could not be restricted to the Dutch situation. These were the technological regimes of aero-engines, household refrigerators and nuclear reactors. None of these three technologies are designed and produced, at least not completely, in the Netherlands. In the case of the refrigerator regime the analysis was concentrated on Germany because an important part of the process of transformation in household refrigerator design took place in that country. For the same reason, the analysis of the nuclear reactor regime focused on the USA. The regime of aero-engines is international in scope, so no specific country was chosen. In three cases - waterside bank constructions, paints and coastal barriers - the regime analysis could be restricted to

the Dutch situation. In the other two cases, chicken husbandry and sewage treatment plants, attention was paid to some international aspects, but only as far as seemed necessary to map these regimes.
After the analysis of existing regimes, the processes of transformation occurring in the different cases were mapped. After a first round of analysis, extra data were gathered if this was necessary to explain the processes of transformation in individual cases or to make comparisons between the cases.

For the data collection, main sources were secondary literature on the existing regimes and all types of texts (from pamphlets to scientific articles) produced by the central actors and interviews. In most cases, several volumes of one or more central journals were surveyed to map the existing technological regime and the process of transformation. Appendix 2 summarizes the sources used for the different case studies.

3.2 Pattern Matching of the Empirically Found Innovation Patterns in the Eight Cases with the Ideal Typical Innovation Patterns

To check whether the selected cases, as depicted in Table 3.1, represented the innovation pattern for which they were selected, pattern matching was applied. Pattern matching is a commonly used method to analyze multiple case studies.[1] It is used to check whether a set of data, a case, matches a beforehand formulated pattern. Table 2.2 defines the variables with which the cases can be matched.
The mapping of the existing technological regimes and their characteristic innovation patterns resulted in descriptions of several pages for each case (Appendix 3). In this section, I present brief summaries of these descriptions. The results of the pattern matching exercise are given in the Tables 3.2 through 3.5. The cases, by and large, matched the innovation pattern for which they were selected.

Supplier-Dependent Innovation Pattern: Paints and Household Refrigerators (Table 3.2)

The regime of paints is characterized by a supplier-dependent innovation pattern. Innovations mainly derive from raw materials developed by suppliers. These suppliers are, as a rule, large science-based chemical firms.
With respect to the paint producers, two types of companies can be distinguished. First, there are about 90 small and medium-sized companies producing paints in the Netherlands. These companies can be characterized as a combination of supplier-dominated firms and specialized suppliers. They mainly produce paints for professional users, like industrial users and professional painters. In the industrial sector, these users together with producers of application apparatus for paint play an important role in the fine-tuning of paint innovations accomplished on the basis of new materials developed by suppliers.
The second type of paint producers is large science-based firms. In the Netherlands, there are two of these: Akzo Coating and Sigma Coatings. In 1990, they accounted for 60% of the domestic sales in paints, a percentage that is rising. These firms

Table 3.2 *Pattern Matching for the Supplier-Dependent Innovation Pattern*

	Type of innovating firm	Type of user	Actors involved in innovation	Typical source/ mechanism of innovation
Expected pattern	Supplier-dominated firms Scale-intensive firms	Anonymous consumers	Suppliers (science-based) (Researchers) Innovating firms	New component parts
Paints	Many small supplier-dominated firms (some characteristics of specialized suppliers.) Some large science-based firms	Anonymous consumers Professional users (professional painters and industrial users)	Suppliers (science-based) Innovating firms (Professional users) (Producers of application apparatus)	New raw materials
Household refrigerators	Scale-intensive firms	Anonymous consumers	Innovating firms Suppliers (science-based and specialized suppliers)	More radical product innovations will presumably derive from the development of new component parts

dominate the do-it-yourself market, play an important role in the building and construction sector and have industrial clients. They produce raw materials themselves and carry out R&D. Nevertheless, also these firms do not produce all the raw materials they use themselves. So, also here innovation is to some extent supplier-dependent.

The producers of household refrigerators are scale-intensive firms. They are large and focus on low-cost production and product differentiation (added features on the basis of more or less standardized models). Consumers are anonymous. As far as product innovation takes place, it comes from inside the firm and from suppliers. Two types of suppliers are important for refrigerator firms. The first type is specialized suppliers. They supply devices like compressor, condensers and evaporators. The larger refrigerator manufacturers usually have more than one supplier of such devices or own such a supplier, as to be not too dependent on individual suppliers. Between these specialized suppliers and the refrigerator firms, a relation of mutual dependency exists.
The other type of suppliers is large science-based chemical companies. They supply the refrigerator firms with coolants, lubricants, isolation materials and plastic for the inner mantle of the refrigerator. Such large science-based suppliers do relatively much R&D - compared with refrigerator firms - on the substances they supply. Since these chemical firms also supply such substances to a host of other customers, it seems likely that refrigerator firms are more dependent on what chemical concerns are willing to supply than chemical concerns are dependent on what refrigerators manufacturers are willing to use. This is especially true for innovations, which imply a change of coolant, the kind of transformation I am interested in in Chapter 4. Chemical firms will presumably take the lead in such innovations. Here, the innovation pattern is clearly supplier-dependent.

User-Driven Innovation Pattern: Chicken Husbandry Systems and Sewage Treatment Plants (Table 3.3)

Both chicken husbandry systems and sewage treatment plants are designed by specialized suppliers. In the past, chicken husbandry systems were designed by the users of these systems, *i.e.* the (poultry) farmers. Since the introduction of the battery cage, the systems are designed and produced by several firms that also produce other mechanical devices for (poultry) farming. As a rule, poultry farmers are no longer directly involved in the design process.
Sewage treatment plants are designed by engineering firms. They usually do so in close cooperation with the instances responsible for sewage treatment in the Netherlands, *i.e.* Water Boards, Treatment Boards and provinces. Sewage treatment plants are built by building contractors.
Innovations in both chicken husbandry systems and sewage treatment plants are usually made by the involved specialized suppliers and research institutes. Contrary to what might be expected, poultry farmers as users are usually not directly involved in bringing about innovations in chicken husbandry design. Water Boards as users are only sometimes involved in innovations in sewage treatment. Nevertheless, in

Table 3.3 *Pattern Matching for the User-Driven Innovation Pattern*

	Type of innovating firm	Type of user	Actors involved in Innovation	Typical source/mechanism of innovation
Expected pattern	Specialized suppliers (Engineering firms)	Professional users	Users (Researchers) Innovating firms	Functional requirements of Users
Chicken husbandry systems	Specialized suppliers	Poultry farmers (Professional users)	(Users) Researchers (Spelderholt) Innovating firms	Guiding principle /Functional requirements
Sewage treatment plants	Engineering firms (specialized suppliers) Water Boards (users)	Water Boards, treatment boards, provinces (Government as client)	(Users) Researchers (STORA) Innovating firms	Functional requirements /mission

both cases, the innovation pattern is user-driven because innovations derive from functional requirements posed by users.
The primacy of user requirements in innovation is reflected in the way sectoral research is organized in both regimes. In both regimes, institutions exist that either carry out or commission practice-oriented research that is (partly) paid by users, and guided by the functional requirements of users. For battery cages, research is mainly carried out by the sectoral research institute *Spelderholt*. In the sewage treatment regime, an important role is played by the STORA since the seventies. This organization is coordinating research for Water Boards that are responsible for sewage treatment. The research funded is carried out by engineering consultants, the Netherlands Organization for Applied Scientific Research (TNO) and universities. New technologies that have not been investigated or have been rejected by the STORA are mostly seen as unproven by Water Boards and engineering firms. Such technologies are seldom applied,
In both technological regimes, technological development is guided by functional requirements posed by users. For chicken husbandry systems, these functional requirements derive from the more encompassing guiding principle of efficiency. This guiding principle has guided chicken husbandry system (battery cage) design, research and use since the seventies.
For sewage treatment plants, functional requirements since the seventies have partly derived from (national) policy documents and legal requirements. Although, Water Boards still have a certain autonomy in formulating effluent standards, this means that requirements increasingly derive from a centrally formulated mission, which is laid down in policy documents and national effluent standards. So, the innovation pattern of the regime of sewage treatment plants has some mission-oriented characteristics.

Mission-oriented Innovation Pattern: Coastal Barriers and Waterside Bank Protections (Table 3.4)

The technological regimes of coastal barriers and waterside bank constructions are part of the Dutch infrastructure sector. In this sector, the government plays a dominant role.[2] It acts as principal of many technical projects, designer/producer, researcher and regulator. In particular, one governmental agency is dominant: Rijkswaterstaat. It acts as principal for most of the larger infrastructure projects in the Netherlands, is involved in the design of technologies for those projects and controls about 70% of the research budgets in the infrastructure sector.[3]
Other important actors in the infrastructure sector are engineering firms, independent research institutes, building contractors and suppliers of construction materials. Most of these actors depend on the government as client. Little incentives exist for the commercial firms involved, especially the building contractors, to invest in long-term research or innovative R&D.[4] Emphasis is on the state-of-the-art. Innovations mainly derive from missions formulated by governmental agencies, preeminently the Rijkswaterstaat.

Table 3.4 *Pattern Matching for the Mission-Oriented Innovation Pattern*

	Type of innovating firm	Type of user	Actors involved in Innovation	Typical Source/mechanism of innovation
Expected pattern	Common good producers	Government as client	Governmental bodies Innovating firms Researchers	Mission
Coastal barriers	Rijkswaterstaat (common good producer) Engineering firms, building contractors (specialized suppliers)	Government as client	Rijkswaterstaat Engineering firms Researchers	Mission
Waterside bank protections	Engineering firms (specialized suppliers) Administrators of bank (users/common good producers)	Government as client (Administrators of banks: *dienstkringen* Rijkswaterstaat, provinces, Water Boards) (Professional) Users	Researchers (Rijkswaterstaat, CUR) Building contractors Suppliers of (construction) materials Innovating firms	Mission/ Functional requirements

The general characteristics of the Dutch infrastructure sector are reflected in the technological regimes of coastal barriers and waterside banks protections. In the regime of coastal barriers, Rijkswaterstaat is the dominant actor. It acts as principal for coastal barrier projects, usually carries out most of the implied design tasks and carries out and commissions research. Other actors involved in the design and construction of coastal barriers are engineering firms and building contractors. These firms are specialized suppliers. Their role in coastal barrier projects is largely determined by Rijkswaterstaat.
Innovations in the regime of coastal barriers are usually accomplished in specific projects. Many projects in the past were carried out at the edges of what was considered technologically feasible at the time and implied a pattern of 'planned innovation.'
Missions for specific projects - and to some extent for the regime as a whole - are defined by the central department of Rijkswaterstaat and the government. Within Rijkswaterstaat, such missions are enforced via the organizational hierarchy. Outside Rijkswaterstaat, missions cannot be enforced via hierarchical lines, but the other organizations involved are often so dependent on Rijkswaterstaat that Rijkswaterstaat can define the framework within which other organizations can contribute to design and R&D activities. So, innovations are usually mission-oriented.

Rijkswaterstaat is also an important actor in the regime of waterside bank protections, although not as dominant as in the regime of coastal barriers. In this regime, Rijkswaterstaat acts as administrator of the larger waterways with national (shipping) functions. Usually, the responsible units of Rijkswaterstaat - the so-called *dienstkringen* - are directly involved in design activities. The Civil Engineering Department of Rijkswaterstaat carries out and commissions research on waterside banks.
Via organizational lines, the central organs of Rijkswaterstaat are to some extent able to formulate missions that guide the actions of the Civil Engineering Department and the *dienstkringen*. This results in a mission-oriented innovation pattern, in which the actual innovations may be accomplished by a range of actors (see Table 3.4).
For waterways administered by other administrators as Rijkswaterstaat, the innovation pattern has some user-driven characteristics because these administrators are more autonomous than the *dienstkringen* of Rijkswaterstaat. Innovations here merely derive from functional requirements of users, *i.e.* the administrators of the bank. An important role in the (development) and acceptance of innovations is also played by the CUR. The CUR is a cooperative body in which the main actors involved in the regime of waterside bank protections cooperate in the carrying out or commissioning of research and in the formulation of design rules and norms.

Table 3.5 *Pattern Matching for the R&D-Dependent Innovation Pattern*

	type of innovating firm	Type of user	Actors involved in innovation	Typical source/mechanism of innovation
Expected pattern	Science-based firms	Mixed	Researchers Innovating firms	New scientific and technological ideas (Presumptive anomalies/promises)
Aero-engines	Science-based firms	Aircraft manufacturers and airlines (Professional users)	Research institutes Innovating firms (New firms)	New scientific and technological ideas (Presumptive anomalies/promises)
Nuclear reactors	Science-based firms	Utilities (Professional users/Government as client)	Research institutes Innovating firms	New scientific and technological ideas (Presumptive anomalies/promises)

R&D-Dependent Innovation Pattern: Aero-engines and Nuclear Reactors (Table 3.5)

Aero-engines and nuclear reactors are both designed by a few large science-based firms. Technological and scientific insights play an important role in the design of these technologies and in the competition between the designer/producers of these technologies. Companies in the nuclear reactor and aero-engine business spend large sums on R&D and the production of innovative designs.

The innovation pattern in both regimes is R&D-dependent. Innovations come in successive generations. Ideas for more radical innovations, which are prototypical for a new generation of products, arise from scientific and technological developments. In the studied regimes, these developments mainly took place in government financed research institutes and in related regimes of military technology. Such research efforts led to what I in Chapter 2 have called technological promises.

Although the companies in the regime of aero-engines and nuclear reactors are very substantial, direct or indirect government subsidies for development costs, and the existence of a governmentally sponsored public research infrastructure are important for the ability and willingness of corporations to innovate. For example, both nuclear energy and civil aviation were not commercially viable in their early days and were only developed because of government subsidies and governmental R&D efforts. Typically, in both the regime of aero-engines and that of nuclear reactors, new technological possibilities were often developed before the need for new functions was clearly established. Nevertheless, in most of these cases, (potential) users became convinced of the need and desirability of the new function, or an alignment with existing functions could be brought about. Appealing promises and large development efforts are, however, no guarantees for successful innovation.

Notes to Chapter 3

1 Yin (1989).

2 Mischgofsky (1991).

3 *Ibid.*, 17.

4 *Ibid.*, 11-12.

4

Substituting Substances

Paints and Household Refrigerators

In the last few decades, environmental sustainability has become a more important design criterion in the technological regimes of household refrigerators and paints, both regimes with a supplier-dependent innovation pattern. This was the result of processes of transformation in both regimes that started when the aggression of the existing technological regimes became manifest.
In the case of household refrigerators, the process of transformation started when CFCs came under fire for their contribution to the degradation of the ozone layer. At that time, CFC 12 was commonly used as coolant in household refrigerators. Due to the ban of CFCs in the late eighties and early nineties, this coolant had to be replaced. Already before the CFC ban, chemical firms developed alternatives to CFCs. They presented the substance HFC 134a as the ideal alternative to CFC 12. Subsequently, this alternative was adopted by refrigerator firms. However, HFC 134a was opposed by environmental groups because of its contribution to the greenhouse effect. Eventually, Greenpeace with the help of a number of other actors succeeded in initiating a second transition from HFC 134a to hydrocarbons like isobutane as coolant. Both transitions - from CFC 12 to HFC 134a and from HFC 134a to isobutane - were ultimately related to environmental design criteria.
In the case of paints, I focus on the reduction of the amount of volatile organic compounds (VOCs) in paints. These substances contribute to smog formation. In the late eighties, the Dutch government started a program to reduce the amount of VOCs in paints. At that moment, paints containing fewer VOCs had already become available thanks to the proactive R&D efforts of chemical suppliers and the larger paint manufacturers. The governmental program aimed at self-regulation by industry and was to promote the further development of paints with fewer VOCs and to stimulate their adoption by users. Also here, the transformation of the technological regime was ultimately related to environmental sustainability as design criterion.

The supplier-dependent innovation pattern of both regimes enabled and constrained the studied processes of transformation. In both cases, suppliers developed new component parts in anticipation of governmental intervention in the technological regime. In this way, suppliers enabled actual intervention by the government because technical alternatives became available that offered governments additional opportunities for intervention. Moreover, the availability of alternatives made it more difficult for the designer/producers of household refrigerators and paints to resist specific changes in the existing technological regimes.
The supplier-dependent innovation pattern also constrained the studied processes of transformation. Technical alternatives that did not fit the interests or R&D capacities of suppliers were more difficult to develop and get accepted, even if they offered better possibilities to take away harmful environmental effects than the alternatives preferred by suppliers.

4.1 Refrigerators Offering Numerous and Valuable Services[1]

The reduction in CFC production and use achieved in the last decade is generally seen as an environmental success story. After the discovery of the hole in the ozone layer in 1985, the production and use of CFCs have quickly diminished and ultimately it was decided to phase out their production and use completely. In this story, I will discuss one regime that was affected by the 'sudden' ban of CFCs: the regime of household refrigerators. CFCs were used in this regime both as coolant (CFC 12) and in the insulation foam (CFC 11). I will restrict the analysis to the substitution of coolants and will focus on Germany. (There are no refrigerator firms in the Netherlands).

At the eve of the debate on the ozone layer, most household refrigerators employed a vapor compression cycle. Important components of such a household refrigerator include the coolant, usually CFC 12 and the compressor. Important design criteria in refrigerator design are reliability, durability, ease of operation, safety and energy efficiency.

Actors playing a role in the regime include household refrigerator manufacturers, chemical suppliers and compressor manufactures. Apart from these commercial actors, also research groups, collaborative organizations and associations, and certification institutions play a role. For innovations implying a change in coolant, one would expect that chemical suppliers supplying the CFCs, like Du Pont, Allied-Signal, ICI, Bayer and Hoechst, would take the first step in the substitution of coolants (Chapter 3).

Box 4.1 *CFCs, HCFCs and HFCs*

CFCs or chlorofluorocarbons consist of Carbon atoms, Hydrogen atoms, Fluorine atoms and Chlorine atoms. They are named as follows: CFC abc, where a refers to the number of C atoms minus 1 (0 means 1 C atom); b for the number of H-atoms plus 1 and c for the number of Fluor atoms. The remaining atoms are Cl. The most important traditional CFCs are:

- CFC 11, mainly used to blow isolation foam and in aerosols;
- CFC 12, mainly used as coolant in refrigerators and in air-conditioning; also used to blow isolation foam;
- CFC 113, 114 and 115, mainly used as solvents and cleaners in the electronics and defense industry.
- CFC (HCFC) 22, used - among other things - for the production of Teflon and as coolant.

The alternatives to CFCs, proposed by the chemical industry, to the CFCs are all HCFCs and HFCs.

HCFCs are CFCs containing at least one hydrogen atom. Due to this H atom, HCFCs are more reactive in the lower atmosphere and are, therefore, less likely to reach the higher atmosphere and to contribute to ozone depletion. The term 'HCFC' was invented after the ozone issue became actual. Some CFCs were then renamed as HCFCs.

HFCs are CFCs containing no chlorine atom. Unlike HCFCs, they have no known contribution to ozone degradation in the higher atmosphere. However, they do contribute to the greenhouse effect.

This story consists of three parts. In Section 4.1.1, I focus on the ban of CFCs and the way in which HFC 134a was developed by chemical suppliers and subsequently adopted by household refrigerator firms. In Section 4.1.2, I describe how Greenpeace, that objected to HFC 134a because of its contribution to the greenhouse effect, succeeded in bringing about a second substitution of HFC 134a by hydrocarbons as coolant. The studied process of transformation will be recapitulated in Section 4.1.3. There, I also discuss to what extent environmental sustainability has become a more important design criterion in the regime of household refrigerators.

4.1.1 The CFC Ban and the Development of HFC 134a as Alternative

In 1970, the British chemist Lovelock was the first to measure CFCs in the (higher) atmosphere.[2] In June 1974, Rowland and Molina published their now famous article in *Nature* about the potential degradation of the ozone layer due to CFCs. This publication and Rowland and Molina's subsequent presentation before the American Chemical Society launched a public and political debate about the use of CFCs. Environmental groups started arguing for a ban on CFCs. By 1978, the use of CFCs in aerosols was banned in the USA and in 1980 the European Community followed by setting a production ceiling for CFCs.[3]

The producers of CFCs reacted in several ways to the ozone debate and the threat of governmental measures. In 1972, nineteen producers of CFCs established the Fluorocarbon Program Panel to pay research on the environmental effects of CFCs.[4] Another reaction of both producers and users of CFCs was to start a lobby campaign against governmental restrictions of CFC production and use. In 1980, 500 companies producing or using CFCs set up the Alliance for Responsible CFC Policy to lobby against CFC measures in the USA.[5] Meanwhile, environmental groups urged for stricter regulation. In 1984, the National Resource Defense Council sued the Environmental Protection Agency (EPA) as to force it to carry out its 1980 plans for stricter control of CFCs.[6]

By 1986, scientific evidence of ozone depletion was rapidly growing and the USA was moving toward possible regulation.[7] The Alliance for Responsible CFC Policy and the world's largest producer of CFCs, Du Pont[8], now gave up their resistance to a production cap on CFCs.[9] In March 1988, Du Pont officially recognized scientific evidence of ozone depletion and it announced to phase out its production of CFCs before 2001.[10] The announced phase-out of CFCs was subsequently taken over by several other chemical firms.[11]

One reason for Du Pont to announce a phase-out of CFCs was that it wanted to prove that it was an environmental consciousness firm.[12] The decision of Du Pont also had other reasons. Du Pont feared that the American government would issue national regulation in the absence of international rules.[13] By proposing a voluntary phase-out of CFCs, Du Pont successfully broke the international industrial front against CFC measures. Now it became more likely that international measures would be agreed upon instead of unilateral US regulation that would harm Du Pont disproportionally. Another reason why Du Pont was willing to phase out CFCs relates to the development of alternatives. In the seventies, Du Pont had already put much R&D

effort in the development of alternatives to CFCs.[14] Between 1980 and 1985, expenditures on alternatives dropped because computer simulations suggested that the ozone layer was not degrading as rapidly as earlier expected. Therefore, no immediate governmental measures were expected. Moreover, alternatives seemed too expensive compared with the CFCs.[15] In 1986, research into alternatives was picked up again. By then, scientific evidence of ozone depletion and the threat of governmental measures were mounting. It seems that by March 1988, some alternatives were so far developed that Du Pont could propose to stop the production of CFC in a number of years, without facing too many commercial disadvantages. A ban of CFCs might even have commercial advantages for Du Pont. Du Pont could now concentrate all its efforts on alternatives to CFCs. A quick ban of CFCs might further offer Du Pont the ability to steer the substitution of CFCs into the direction of alternatives that were easy to patent and had a relatively large added value. For chemical firms like Du Pont, it would not have been attractive if CFCs were substituted by chemicals that are easy to be made and, therefore, inexpensive. In the case of CFC 11 and CFC 12, which had become commodity chemicals over the years, alternatives might even be more profitable for Du Pont and the rest of the chemical industries than the existing CFCs.[16]

In the late eighties and early nineties, national and international measures to reduce and eventually ban the production and use of CFCs quickly followed on each other. In 1987, the Montreal Protocol was concluded, calling for a substantive reduction in the use and production of CFCs for all kinds of applications. International conferences following the Montreal Protocol recommended yet tougher measures. By 1992, the European Community was moving toward a complete ban on CFCs, as of January 1995.[17]

The CFC Issue Reaches the Agenda of the Refrigeration Regime[18]

From the early eighties on, CFCs were increasingly recognized as a major issue in relation to (household) refrigeration design. In the first instance, the CFC issue was discussed in the regime of refrigeration that also encompasses the design of refrigerating apparatus for such purposes as ice-making, brewing and the storage of meat.

In 1983, the need to reduce CFC emissions was discussed at the sixteenth congress of the International Institute of Refrigeration (IIR). At that moment, new computer simulations suggested that the degradation of the ozone layer was not proceeding as rapidly as had originally been assumed.[19] In line with this finding, it was concluded at the 1983 IIR congress that the degradation of the ozone layer - if taking place - was a slow process. No need for tight governmental measures existed.

In 1985, the hole in the ozone layer was discovered. This immediately restored the ozone issue to the international agenda. Now, the use of CFCs became a more immediate concern in the refrigeration regime. According to the IIR, the solution to the CFC problem should be sought in the prevention of leakages from refrigeration systems. An editorial in the *International Journal of Refrigeration* stated it as follows:

We would be wise to concentrate our attention on methods of reducing leakages, and of finding ways of avoiding blowing refrigerants to waste when repairs or alternations are required to systems. Then we would have irrefutable evidence on which to stake our claim for continued use of CFCs.[20]

By 1986, CFCs were recognized as a problem in the refrigeration regime. The solution should be found in recovery and recycling. Feasible alternatives were believed not to be available, so more research should be done first. Further, the greenhouse effect was mobilized as argument to pay more attention to the energy efficiency of cooling systems and less to the choice of coolants.[21]
After the Montreal Protocol was concluded in 1987, the argument that the solution to the CFC problem could be found in recycling and the reduction of leakages became less and less credible. The IIR now increasingly became convinced that finding alternatives to CFCs was necessary. Measures against CFCs were no longer opposed, only the 'tight' time schedules were attacked. Meanwhile, several environmental groups raised the fundamental question whether the world really needed as much cooling capacity as it then possessed. In 1989 Director Gac of the International Institute of Refrigeration (IIR) reacted to such attacks as follows:

[T]he question I am often asked, and that is considered to be embarrassing for the IIR Director, concerns the chlorofluorocarbons . . . I am asked what the refrigeration engineers will do in order to reduce and control chlorofluorocarbon emissions . . . In fact this is an excellent question: the CFCs emissions are one of the best means we have at our disposal today, to remind us today that the refrigerating machines, which are very reliable, offer numerous and valuable services . . . If a decision had been made, at an international level, of forbidding immediately any CFCs emission, it would have created such troubles in the supply of perishable goods that not only would the cost of living have increased suddenly and dramatically, but also underfeeding and malnutrition would have worsened, notably in the countries already underprivileged.[22]

As this quotation shows, the legitimacy of the hegemonic design of refrigerating apparatus was under so much public and political pressure that a representative of the IIR felt obliged to articulate the legitimacy of the existing regime. However, he and others could not prevent governments from passing tighter measures.[23]

Household Refrigerators; the Development of HFC 134a as Alternative Coolant[24]

Developments in the regime of household refrigerators reflect the described pattern in the larger regime of refrigeration. When CFCs came under serious attack, the household refrigeration industry began to investigate various alternatives to the coolant CFC 12. In Germany this process started in the mid eighties.[25] In 1986, the West German branch organization of the white good manufacturers - the ZVEI - established a working group to assess various alternatives to CFC 12.[26] This working

group included firms like Bosch-Siemens, Liebherr, AEG, Bauknecht and Miele. A reason for cooperation was that the chemical industry would probably supply all refrigerator firms with the same alternative coolant.
The chemical industry indeed presented one alternative as *the* substitute of CFC 12.[27] This coolant was HFC 134a, a substance that was easy to patent and not too inexpensive. So, it was attractive for the chemical industry. HFC 134a was first put forward by Du Pont and ICI; later they were joined by other chemical firms.
HFC 134a is nontoxic, nonflammable, chemically stable and its thermodynamic properties are slightly worse than those of CFC 12.[28] These qualities made it attractive as substitute to CFC 12. However, HFC 134a also had several disadvantages. It is sensitive to moisture in the cooling system and it required (major) changes in the compressor and lubricants. For the refrigerator firms, a further disadvantage might have been that it was relatively expensive.
The working group of the ZVEI did not simply follow the decision taken by the chemical industry.[29] It decided to assess alternatives to CFC 12 independently and excluded the chemical industry from its strategic meetings. Nevertheless, by 1990 consensus was reached that HFC 134a was the most fit alternative among the many coolants assessed.[30] This decision was partly due to the technical advantages of HFC 134a. However, the choice for HFC 134a did not solely rest on its optimal technical features. (Remember that HFC 134a also had some technical disadvantages). HFC 134a was also chosen because it neatly fitted the existing customer-supplier relations. Given the marked preference of the chemical industry for HFC 134a, this industry would clearly supply this coolant, adapt lubricants for compressors to HFC 134a and possibly offer further technical assistance.[31] Moreover, most compressor companies followed the chemical industry’s lead by adapting their compressors to HFC 134a.[32] Finally, also much research at universities and other research groups - either funded by governments or commercial firms - concentrated on HFC 134a. In the late eighties and early nineties, many chemical firms, household refrigerator firms, compressor producers and researchers thus concluded that HFC 134a was best fit for substituting CFC 12 as refrigerant. Nevertheless, some actors criticized the choice of HFC 134a.

In 1988, a conference on CFCs and alternative coolants was organized in Purdue. At this conference, the choice of HFC 134a was questioned.[33] Ammonia and hydrocarbons were mentioned as possible alternatives. Hydrocarbons were known as having good thermodynamic qualities, but they are flammable. Especially in the USA where refrigerator manufacturers can be sued for accidents due to design or production mistakes the use of flammable coolants is not popular.[34] Moreover, refrigerators with flammable coolants might not be able to get the safety approval of certification institutions. Nevertheless, at the Purdue Conference some participants believed that hydrocarbons could be feasible alternatives to CFC 12.
Also at other occasions, other alternatives than HFC 134a were proposed. Authors in the *International Journal of Refrigeration* have paid attention to coolants like ammonia and, since 1992, hydrocarbons.[35] In some governmentally financed research programs, alternative coolants and alternative cooling cycles received attention.[36]

The most fervent opponents of HFC 134a were environmental groups. They opposed HFC 134a because it contributed to the greenhouse effect. Some of these groups proposed the use of alternative coolants. Dutch environmental groups like *Natuur & Milieu* (Nature & Environment), the *Zuidhollandse Milieufederatie* and Greenpeace have advocated the use of HFC 152a instead of HFC 134a.[37] The reported contribution of HFC 152a to the greenhouse effect is more than eight times as low as HFC 134a.[38] Moreover, HFC 152a was claimed to be more energy efficient than HFC 134a.[39]

The US Environmental Protection Agency (EPA) as well expressed a preference for HFC 152a over HFC 134a.[40] However, chemical firms rejected HFC 152a because of its flammability. They also claimed that the use of HFC 152a would decrease the energy efficiency of a refrigerator. Typically, most refrigerator firms were not enthusiastic about alternative coolants claimed to be either less energy efficient or flammable.[41] So, refrigerator firms stuck to HFC 134a as alternative.

The First Step Into a New Age of Refrigerants?

The choice for HFC 134a as an environmentally superior substitute to CFC 12 by the household refrigerator industry was conditioned not only by favorable technical specifications (good thermodynamic properties, nontoxicity, nonflammability and chemical stability) but also by the economies of maintaining existing supplier-customer relations. Technically the use of HFC 134a was not without disadvantages; the compressor and the lubricants had to be adapted. However, such adaptations could be achieved within the existing supplier-customer relations.

The development of HFC 134a thus reflected the existing technological regime and its supplier-dependent innovation pattern. The lead in the innovation process was taken by chemical firms. The actual substitution was usually achieved in close cooperation between refrigerator firms, the chemical industry, and the suppliers of compressors.[42]

In two respects the substitution of CFC 12 by HFC 134a differed from normal innovations in the refrigerator regime. One was the large role of regulatory pressure in the innovation process, the other the emphasis on environmental concerns as design criteria. Both followed on the actions of critical scientists and environmental groups who, by their actions, made a harmful environmental effect of the regime of household refrigerators manifest.

Without governmental interference, the substitution of CFC 12 would probably have been much slower or totally absent. For many within the regime, the amount of energy mobilized to find an alternative to CFC 12 was amazing. In 1990, the editor of the *International Journal of Refrigeration* expressed it as follows:

> *In my nearly 25 years of working with the heating, ventilating, air-conditioning and refrigeration industry . . . , I have never seen this industry put so much time and effort into one problem as they have into the CFC problem. It is doubtful that any refrigerant, including R12 and R22, has been tested more in as short a period of time as 134a. Never before in the history of this industry, over a 3-5 year time period, has so much been*

written and published on one subject as this industry has produced on the CFC problem and possible solutions.[43]

Given that the CFC 12 had been the coolant of choice for refrigerators since the thirties, the quick introduction of HFC 134a was indeed radical. HFC 134a was believed to be ‘the first step into a new age of refrigerants.’[44] But the already mentioned opposition of environmental groups was to block a smooth transition, at least in some countries.

4.1.2 The *Greenfreeze*[45]

In 1989, the refrigeration system of the Dortmund Institute of Hygiene had to be replaced. Director Rosin of the institute and his assistant Preisendanz rejected the existing coolants because of their environmentally harmful effects (contribution to the degradation of the ozone layer and contribution to the greenhouse effect).[46] To find alternatives, they started experimenting with hydrocarbons as coolant. The idea to use hydrocarbons for this purpose was not entirely new. Early in the twentieth century, hydrocarbons had incidentally been used as coolant and the excellent thermodynamic properties of hydrocarbons were well known. Moreover, hydrocarbons are cheap. After a year of experimenting, Rosin and Preisendanz successfully developed a mixture of three hydrocarbons that could function as coolant. For their efforts, they won an environmental prize.

The Dortmund Doctors - as Rosin and Preisendanz were soon called - initially did not aim at influencing the technological regime of household refrigerators, but by 1991 they began to realize that their ‘invention’ might be relevant for this regime. Members of Greenpeace met doctor Preisendanz in 1990 or 1991. Greenpeace was immediately very interested in the mixture developed by the Dortmund Doctors. At that moment, Greenpeace was in the midst of an intensive campaign against HFC 134a.[47] Greenpeace recognized the mixture as a means to prove that environmentally benign alternatives to HFC 134a did exist.

After the meeting with the Doctors, Greenpeace tried to find a German refrigerator manufacturer to commercialize the hydrocarbon mixture. None of the refrigerator firms was interested. One reason for the unwillingness of the refrigerator firms to try out the Dortmund mixture was that tests, carried out in 1991, showed that a refrigerator using this mixture consumed 38% more energy.[48] Although Greenpeace disputed the outcomes of these tests and that also Professor Gorenflo who participated in carrying out the tests dissociated himself from the results, the refrigerator industry considered the mixture too energy-consuming.[49]

The refrigerator firms also feared the flammability of hydrocarbons. Since the large-scale introduction of CFCs, flammable refrigerants were seen as unacceptable for household applications. Acquiring a safety approval for a refrigerator with flammable coolants might be more difficult. On the other hand, evidence existed that the safety of refrigerators with hydrocarbons as coolant was a resolvable problem.[50] A final reason, named by professor Lotz of Bosch-Siemens, not to test the hydrocarbon mixture was that Rosin and Preisendanz wanted to keep secret the exact composition of their mixture.[51] This made it impossible for the refrigeration industry to test the mixture in their own labs.

In February 1992, Greenpeace found a company willing to try hydrocarbons as coolant: DKK Scharfenstein, a refrigerator firm from the former DDR. Before the unification of Germany, DKK had had a monopolistic position on the East German market for household refrigerators. In 1992, after the unification of Germany, the economic position of the firm had become deplorable. Sales dropped by almost 80% between 1990 and 1992.[52] The company hoped to be taken over by Bosch-Siemens. However, negotiations between Bosch-Siemens and Treuhand, the state holding agency responsible for the former DDR firms, failed. DKK would probably go bankrupt. In these circumstances, the offer from Greenpeace - to pay the development of ten prototypes with hydrocarbons as coolant - was regarded a mercy.
DKK saw the development of a more environmentally benign refrigerator as a means to enlarge its market share. Technically, the use of hydrocarbons as refrigerant was received with mixed feelings. On the one hand, DKK had problems with the implementation of HFC 134a. One of the problems concerned the compressor. DKK produced its own compressors and was not (yet) able to modify its compressors optimally to HFC 134a.[53] Perhaps, hydrocarbons could offer a solution to these problems. On the other hand, the use of *flammable* coolants was received very skeptically at DKK.
In a relatively short time, DKK succeeded in developing a refrigerator with the hydrocarbons propane and butane as coolant. The Dortmund mixture was not used because producing commercially a mixture of three gases in the right composition was very difficult.[54] Moreover, by mixing propane and butane a coolant could be made which physical properties that were quite similar to CFC 12.[55] So, few adaptations in especially the compressor were required.[56]
In July 1992, DKK claimed to have achieved energy parity between propane/butane and CFCs. Almost at the same moment Treuhand declared that DKK Scharfenstein had to be wound up. After intervention of Greenpeace and the German Minister of Environment Töpfer, Treuhand was prepared to give DKK a last chance. It announced to guarantee 540 jobs at DKK until the end of 1993. Moreover, Treuhand invested five million DM for the development of the Greenpeace refrigerator that was now called the *Greenfreeze*. Later, DKK was bought by the London East German Investment Trust and renamed as Foron.
In August 1992, Greenpeace started a publicity campaign with the prototypes built at DKK. The campaign was very successful. In two weeks, 50,000 orders were placed for the *Greenfreeze* of which 20,000 were collected by the mail-order company Neckerman. The total number of orders amounted to 65,000. According to a poll 77% of the Germans favored the *Greenfreeze*.[57] DKK now decided to start serial production.
The first reaction of the other German manufactures of refrigerators, organized in the *ZVEI*, was a complete disapproval of the use of hydrocarbons. The seven largest refrigerator firms sent a letter to retail trade in September 1992 in which they insisted that the energy use of the *Greenfreeze* was too high.[58] Moreover, they proclaimed that the use of hydrocarbons as coolant was not yet proven. Managing

director Günther of DKK endured this rejection also personally. He describes a meeting of the *ZVEI*, after the launching of the *Greenfreeze* by DKK, as follows:

> *Trafen wir uns da ... Leute, die ich von der Vergangenheit kannte ... und eine ganze Menge vernüftiger Gespräche mit geführt hatte; plötzlich gingen alle auf Distanz. Wir wurden behandelt bei ZVEI als ob wir verrückt wären oder eine ansteckende schlimme Krankheit hätten .... Rechts und links war ein Platz frei; niemand setze sich zur mir. ... Nur wenige fanden sich bereit, uns ein Hand zu geben ... .*[59]

Despite this reaction, the German refrigerator manufactures started testing hydrocarbons as coolant in their own labs. Some of them, like Bosch-Siemens and Liebherr, even invited Greenpeace to discuss the issue.

The popularity of the *Greenfreeze* was not only due to the Greenpeace campaign, but also to the David and Goliath-character of the quarrel between DKK and the other refrigerator firms. The defaming of the *Greenfreeze* by the ZVEI had adverse effects: it moved public sympathy to the side of DKK and Greenpeace. DKK was seen as a David from East Germany fighting to hegemony of the Western German companies.

In December 1992, the *Greenfreeze* acquired the safety approval from the *TÜV* (the Technical Certification Institute in Germany). The *Greenfreeze* also acquired the European safety certificate 'EC Standard for Electrical Equipment 72/23/EEC'. This showed that a refrigerator with flammable coolant could comply with existing safety standards.

Once it was clear that refrigerators with hydrocarbons were not only technically possible, but were also safe and appreciated by the consumer, the other German refrigerator manufacturers quickly developed their own refrigerators with hydrocarbons. They usually chose isobutane as coolant. Using this coolant required some adaptations in the compressor, but this problem proved not too difficult to overcome technically. Moreover, now that the large German refrigerator manufacturers were clearly interested in isobutane as coolant, compressor manufacturers like Danfoss began to adapt their compressors to isobutane.[60]

In February 1993, Bosch-Siemens, Liebherr and Miele presented a refrigerator with isobutane as coolant at the Domotechnica in Cologne. Other companies like AEG did not want to switch to isobutane because they were convinced that refrigerators using hydrocarbons consumed more energy. These firms argued that, for this reason, the total contribution to the greenhouse effect of refrigerators with isobutane was higher than that of refrigerators using HFC 134a.[a] However, these firms did not succeed in convincing the public with this argument and, fearing a negative public

a I have no data on the relative energy consumption of refrigerators using isobutane and refrigerators using HFC 134a. Contrary to AEG, most refrigerators firms and other actors involved claim that refrigerators with isobutane are at least as efficient as those with HFC 134a.

image and declining sales, they decided to switch to isobutane as refrigerant as well. Jürgensen of AEG expressed his feelings about this decision as follows:

> *The environmental impact of a refrigerator or freezer is still mainly affected by the energy consumption, as shown in TEWI [Total Equivalent Warming Impact, IvdP] balances, so R134a is named to be good from political authorities in Germany, Sweden, Denmark and other countries, but a home appliance manufacturer has to produce for the market needs.*
> *AEG is producing refrigerators and freezers with isobutane as refrigerant where the efficiency is at least comparable and the risk for the consumer is at minimum.*[61]

By 1994, all German manufacturers were producing refrigerators with hydrocarbons as coolant. Also other European companies like Electrolux, Quelle and Vestfrost have developed refrigerators with hydrocarbons as coolant. Such refrigerators are now on sale in Germany, Austria, Denmark, France, Italy, the Netherlands, Switzerland and Britain. In the Netherlands, the HFC-free refrigerator was the only type of refrigerator to get an eco-label. According to Greenpeace, refrigerators with hydrocarbons as coolant had a market share of more than 50% in the Netherlands in 1995.[62]
Outside Europe, there also has been interest in hydrocarbons as coolant. A Chinese company expected to start the production of refrigerators with hydrocarbons as coolant in February 1995.[63] Some third world countries are also interested. In the USA, the technology is not yet introduced. US refrigerator companies have argued that the 'hydrocarbon technology is not compatible with the large size and the automatic defrost features of American refrigerators.'[64] Moreover, American refrigerator firms are more anxious for flammable coolants given the product liability rules in the USA. Nevertheless, Greenpeace is optimistic about the acceptance of hydrocarbons as coolant in the USA:

> *Despite the U.S. industry's current resistance to switching to 'Greenfreeze' technology, Greenpeace is confident that 'Greenfreeze' has a bright future in the American market. This optimism is based on the inherent environmental and technological advantages of hydrocarbon refrigeration over HCFC and HFC based technologies. These substances have a time-limited market potential because of their negative impact on the environment, and they are more expensive and less efficient than hydrocarbons.*
> *Furthermore, indications are that despite vested interests promoting the HCFC and HFC technologies, there is considerable interest on the research level in 'Greenfreeze' technology among American manufacturers. Greenpeace believes that it is only a matter of time before the technology penetrates the North American continent, and that the company that makes the first move will gain the greatest commercial benefits.*
> *The future of 'Greenfreeze' in North America will ultimately be decided by the consumers. North American consumers are just as sophisticated and*

environmentally conscious as their European counterparts. Soon the major manufacturers will realize that a domestic 'Greenfreeze' refrigerator offers huge market potentials.[65]

Whether Greenpeace's optimism is justified will the future show. However, clearly the process of transformation toward hydrocarbons as coolant did not stop at the German borders.

4.1.3 Transformation of the Technological Regime of Household Refrigerators

In the early nineties, the transition from CFC 12 toward HFC 134a as coolant was conceived as a small revolution within the technological regime of household refrigerators. This transition was the result of a process of transformation initiated by concerned atmospheric scientists and environmentalists. In this process, governments played a crucial role by eventually banning CFCs.
Government regulation was enabled by the fact that chemical firms had proactively developed alternatives and had spoken out to be prepared to stop the production of CFCs. What we see at work is a dynamics of expectations. Chemical firms began to develop alternatives in anticipation of expected future regulation. By developing these alternatives, they enabled actual regulation. It is less likely that governments had decided for a ban if no alternatives had been or could soon come available. So, the proactive policy of chemical suppliers helped - intentionally or not - to make the expectation of regulation come true.[a]

The lead in the substitution of CFC 12 was taken by the chemical industry. This industry put forward HFC 134a as the alternative to CFC 12. This choice was subsequently taken over by refrigerator firms, governments and compressor manufacturers. Why did these actors follow the choice of the chemical industry? Refrigerator companies depended on chemical firms for the supply of alternative coolants and accompanying lubricants for the compressor. In Germany, the refrigerator manufacturers believed that the chemical industry would supply only one alternative coolant for household refrigerators. Therefore, they set out a collective strategy to select one alternative coolant. They selected HFC 134a. One reason to do so was that the car industry decided to switch to HFC 134a as coolant for air-conditioning.[66] So, HFC 134a would be available. Apparently, the refrigerator firms doubted whether they could - even collectively - overcome their dependency on the chemical industry. They did not want to put the existing supplier-customer relations at risk. HFC 134a has some disadvantages, but these were surmountable for them.

a Of course, other factors played a role in the actual formulation of regulation like the perceived gravity of the environmental problem and the possibility to reach international agreement. Moreover, the willingness of especially Du pont to stop CFC production was related to somewhat contingent factors like impending American regulation in absence of international regulation.

Actors like compressor manufacturers and governments also in some respects depended on the chemical industry. Therefore, they also chose to jump the HFC 134a bandwagon. Governments depended on industry for the implementation of the Montreal Protocol and other anti-CFC measures. Most governments aimed at cooperation with industry; too much resistance to HFC 134a might undermine this strategy. Nevertheless, some governments financed research into other alternatives. Compressor manufacturers mainly followed choices made by the other industrial actors and adopted their compressors to HFC 134a. Mostly, this was done in close cooperation with refrigerator manufacturers and chemical firms.
Refrigerator firms, compressor manufacturers and governments not only accepted HFC 134a because they depended on the chemical suppliers for the development and availability of technical alternatives. They also considered the technical and environmental properties of HFC 134a acceptable. In the event, the disadvantages in terms of required technical adaptations and contribution to the greenhouse effect were traded off against advantages in terms of availability (refrigerator firms) and the implementation of the CFC ban (governments).

The choice of HFC 134a then was path-dependent.[67] Due to the existing supplier-dependent innovation pattern, suppliers took the lead in proposing new coolants. Much R&D had already been done on HFC 134a before other actors entered the scene. So, HFC 134a had a competitive advantage over other coolants when other actors - besides the chemical industry - became interested in alternative coolants. This made it attractive for those other actors to join the efforts on HFC 134a. In this way, they further enlarged the (R&D) efforts going into HFC 134a and so enlarged its competitive advantage, now also in terms of governmental acceptance, adaptation of compressors et cetera. So, HFC 134a was not superior from the start, it became so - at least in the eyes of most actors involved - because most efforts concentrated on this coolant. A lock-in in HFC 134a was the result.
This lock-in was eventually overcome by Greenpeace, in cooperation with the Dortmund Doctors and DKK Scharfenstein (Foron). They did so via the mobilization of user pressure, by that using the - until then rather latent - dependency of refrigerator firms on their (anonymous) consumers. This dependency was latent in the switch from CFC 12 to HFC 134a because refrigerator firms intended to make this transition invisible for their consumers, except perhaps from a sticker with the text: 'This refrigerator does not contain CFCs.' Properties of the new refrigerator like contribution to the greenhouse effect would be blackboxed for the consumer.[68] So, consumers could not select refrigerators in this respect.[a]
Greenpeace could try to unblackbox the contribution of the new refrigerators to the greenhouse effect, but it would be especially successful if it could offer consumers an alternative. This would require the development, production and sale of an

a Environmentally conscious consumers might know that HFC 134a contributed to the greenhouse effect and via the manual of the refrigerator, for example, they might find which refrigerators used HFC 134a. This route, however, requires much effort from the user/consumer. Moreover, as long as all refrigerators contain either CFCs or HFC 134a, there still is little to choose for environmentally conscious consumers.

alternative refrigerator using an alternative coolant. In this respect, Greenpeace depended on industry. When DKK Scharfenstein was prepared to develop the *Greenfreeze* for Greenpeace and did so successfully, this implied an important breakthrough in the dependencies between Greenpeace and the refrigerator firms. Before, Greenpeace depended on the refrigerator firms for the development of a feasible alternative refrigerator using a more environmentally sound coolant. Once the *Greenfreeze* was developed, Greenpeace possessed a means to mobilize consumers against the other refrigerator firms. It was so successful in doing so, that Greenpeace was more or less accepted as representative of consumer demands on refrigerators, at least with respect to the environmental soundness of coolants. Now, at least for the time being, refrigerator firms depended on Greenpeace to get their refrigerators accepted as environmentally sound. This also explains why some refrigerator firms started talks with Greenpeace. Firms that objected to the use of hydrocarbons eventually also had to give in, fearing a loss of market share.

What lasting transformations has the described process of transformation brought in the technological regime of household refrigerators? One important transformation is the growing importance of the design criterion environmental sustainability. Environmental sustainability was an important criterion in the choice of isobutane. Of course, the earlier substitution of CFC 12 by HFC 134a was also motivated by environmental concerns about the hole in the ozone layer. Nevertheless, the contribution of HFC 134a to the greenhouse effect was, in the event, traded off against advantages like profitability (for the chemical firms), availability (for the refrigerator firms), ease of implementation of a CFC ban (for governments) and nonflammability. The contribution of HFC 134a to the greenhouse effect was thus treated as an unavoidable secondary effect.[69] This is in contrast with the choice for hydrocarbons as coolant. Hydrocarbons as coolants were proposed, first by the Dortmund Doctors and later by Greenpeace, because they had fewer environmental disadvantages.

Environmental sustainability then was not an entirely new design criterion in the transition toward isobutane.[a] However, this criterion certainly got more weight vis-à-vis other design criteria than before. This is clearly visible in the adoption of isobutane. Isobutane implied that new tradeoffs in terms of flammability had to be accepted. This was not easy, since nonflammability was generally accepted as design criterion for coolants in the technological regime of household refrigerators. This criterion was, moreover, embedded in technical norms and certification procedures. Nevertheless, the use of isobutane in household refrigerators could be proved to be safe and was accepted by certification instances and refrigerator firms, at least in Europe.

a The criterion environmental sustainability is in itself somewhat vague. In the refrigerator regimes it relates to measures like the ODP (Ozone Depletion Potential) and the GWP (Greenhouse Warming Potential) of coolants and to efficiency of the refrigerator. The exact translation of environmental sustainability into design requirements is, however, not clear-cut and a point of dispute (as is exemplified by the dispute over the Total Equivalent Warming Impact (TEWI) of coolants).

At the moment, several further developments are underway in the regime of household refrigerators motivated by the striving for environmental sustainability. First, parallel to the described process of transformation, CFC 11, used to blow the insulation foam of refrigerators, was subsequently replaced by HFC 134a and cyclopentane.[70] These transformations much resemble the ones I described with respect to CFC 12 as coolant.

Another interesting development is the development of very energy efficient household refrigerators. Probably, the most radical proposals for such refrigerators come from several actors that play a marginal or no role within the existing regime. This includes actors like Sunpower Inc., Renewable Energy Systems, Foron and Greenpeace.[71] They have proposed a refrigerator using a Stirling cycle instead of the conventional vapor-compression cycle. Technically, the switch to such a refrigerator would be much more radical than the transition toward isobutane as coolant. Such a refrigerator may also introduce new tradeoffs in terms of performance and, hence, be less easily accepted by consumers.

Typically, radical new types of refrigerators like the Stirling machine are hardly considered and researched by refrigerator firms (apart from Foron) and their suppliers. Refrigerator manufacturers, as before, seem to focus on process innovation and production differentiation in terms of added features to more or less standardized designs. Reduction of energy consumption is a major goal, but not by means of radically different refrigerator designs.

4.2 Environmentally Sound Paints

Attention for the nuisance and the negative health effects of paints is centuries old. Already in the seventeenth and eighteenth century, negative health effects of paints sometimes resulted in (governmental) regulation.[72] In the seventies of this century, attention in the Netherlands began to focus on the wider environmental effects of paints. In the early seventies, the environmentalist Copius Peereboom accused the paint industry of releasing annually 80 tonnes of mercury into the environment.[73] In reaction to the resulting public anxiety, the association of Dutch paint producers, the VVVF, began to develop an environmental policy.[74] In consequent years, a number of environmentally harmful substances in paints - like heavy metals and asbestos - would draw attention and the amount of them in paints would be reduced.[75]

In this story, I focus on the reduction of VOCs in paints. VOCs are volatile organic compounds, like hydrocarbons. They became commonly used as solvents in paints in the course of the twentieth century. VOCs are reported to contribute to the Chronic Painters Syndrome, a neuropsychological disease that damages the brain and the central nervous system. The existence of this contribution is, however, disputed by some scientists.[76] VOCs also contribute to the formation of smog. It was especially the latter secondary effect, which led to attempts to reduce their amount in paints.[77]

The process of transformation toward paints with a lower VOC content was initiated by worried outsiders like environmentalists. In the Netherlands, the process of transformation really took off when the government became involved in the reduction of VOC emissions. In 1985, the Dutch government formulated as policy goal a reduction of 50% of the amount of VOCs in paint by 2000, as compared to 1981.[78] The program KWS 2000 (Hydrocarbons 2000) was established to reach this goal. The program was based on self-regulation by the paint industry and it started in 1989. At that moment, a number of paints with a lower VOC content already existed. In 4.2.1, I describe how these alternatives were proactively developed by suppliers and the larger paint producers. In the next section, I discuss why KWS 2000 was formulated in terms of self-regulation and did not imply a ban on VOCs. In this section, I also discuss the further development and acceptance of paints with fewer VOCs. Finally, in 4.2.3, I recapitulate the process of transformation.

4.2.1 The Development of Paints with a Lower VOC Content

In the Netherlands, paints are produced by about 90 small and medium-sized companies and two large science-based firms, Akzo Coatings and Sigma Coatings.[79] Raw materials are supplied by chemical firms, which are usually large and science-based, do a lot of R&D and deliver also guidelines for recipes to paints producers. Both Akzo and Sigma Coatings are part of a larger chemical concern and so produce part of the raw materials they use themselves.
The main functions of paints are the protection and embellishment of surfaces.[80] General design criteria, related to protection, are the durability and protection against water, UV radiation, scratches and spots. Design criteria, related to embellishment include color, gloss and permanence. Design criteria relating to applicability include flow, spreadibility, drying time, elasticity and hiding power. The performance of paints is to an important degree dependent on their composition.[81] The major components of paints are given in Box 4.2. For technical

Box 4.2 *Main Components of Paints*

- *The medium or binding agent.* The medium forms the coating film after the paint has dried. Linseed oil, sometimes reinforced with natural resins, was mostly used as medium until well into the twentieth century. Nowadays, synthetic resins like alkyds and acrylates are generally used as medium.

- *Pigments.* The pigments determine the color and the opacity of a paint. Traditionally, 'natural' pigments were used, which were produced in special mills. Examples are madder, white lead, and indigo. In the twentieth century, many new synthetic pigments have been developed and come into use.

- *Solvents.* This is the medium in which the other substances (pigments, medium, additives, fillers) are dissolved. Traditionally terpentine was commonly used as solvent. Nowadays, volatile organic compounds like white spirit are commonly used solvents; water is also sometimes used. Since most (synthetic) resins are not dissoluble in water, water-based paints are often emulsions.

- *Additives and fillers.* Additives are added to paints to fulfill specific functions, like the enhancement of drying, the better dispersion of the pigments and the prevention of bacterial attack. Fillers are dispersed in the medium in order to improve its performance (hardness, density) and to fill irregularities in the surface to be painted.

reasons, replacing or reducing the solvent (VOCs) in paints is not possible without changes in the other paint components. Therefore, the development of paints with fewer VOCs requires the development of new raw materials by suppliers. So, like regular innovations in the technological regime of paints, the development of paints with fewer or no VOCs was supplier-dependent.
Suppliers began to develop new raw materials for paints with fewer or no VOCs in the fifties and sixties, mainly in anticipation of American regulation. In 1966, a rule was issued in California to regulate VOC emissions.[82] California was one of the first regions in the world to suffer from large-scale smog problems due to its specific geographical and climate conditions. California Rule 66 led to the development of paints containing less VOC and it triggered regulation in other US states.
Because of the sketched developments, several paints containing fewer solvents came available in the seventies and eighties. The most important were water-based paints, high solids and powder coatings (see Box 4.3).[83] All these paints required the development of new raw materials, especially new binding agents, new additives and new (reactive) solvents.

In the Netherlands, paints with fewer VOCs have been developed since the seventies.[84] Initially, environmental concerns were not a main motive for the development of such paints. Instead development and use of these paints were usually related to advantages that were application-specific or due to specific local circumstances. For some industries, water-based paints were attractive because they reduced the cost for fire insurances or made it easier to apply for a hindrance permit at the local authorities. Another reason to develop water-based paint was the superior painting performance on some materials.[85]

Box 4.3 *Developed Alternative Paints With Fewer or No VOCs*

- *Water-based paints* are paints in which the VOCs are - partly - replaced by water. This requires the use of different binding agents and of different stabilizers and other additives. The use of organic co-solvent is often necessary too. Water-based paints contain up to 15% of organic (co)solvents, whereas traditional alkyd paints contain about 40% organic solvents.
  Different kinds of water-based paints are now available. They are available for application by brush, roller and for industrial use. Water-based paints are either based on acrylate resins or alkyd resins or both; the latter are known as hybrid paints. Recently, DSM Resins has claimed to have developed an alkyd resin that can be used to formulate water-based paints without solvents.

- *High solids* are paints which contain fewer solvents (about 15-25%). These paints require (alkyd) resins with a lower molecule weight and organic solvents that are more reactive (‘aggressive’) than the conventional VOCs like white spirit. High solids have been developed for both application by brush and roller and for industrial use.
  High solids without solvents have also been developed. So-called two component systems provide an example. Such systems consist of a resin and a curing agent. If they are brought together, a reaction takes place resulting in the formation of a coating film.

- *Powder coatings* contain no solvents. They cannot be applied by brush or roller, and are only apt for industrial applications. An application technique for such paints is electrostatic spraying. An advantage of powder coatings is that they can be more efficiently applied than traditional paints and that spilt paint can be recovered.

Since the early eighties, the reduction of organic solvents in paints has become a goal on itself in the Dutch technological regime of paints.[a] Increasingly, paints with fewer or no VOCs were conceived and developed as possible substitutes for existing solvent-based paints. Especially the large and medium-sized companies began to develop paints with fewer or no VOCs. They did so in anticipation of governmental regulation and market demand.[86] Market demand was, and is, often related to governmental policy because many industrial applicators and users of paints are, confronted with restrictions in VOC emissions due to governmental policy or tighter requirements for the acquisition of (local) permits. Further, VOC measures in other countries created market demand for companies exporting paints, as many Dutch paint producers do.

The quality of paints with no or fewer VOCs is disputed. Especially water-based paints have been accused of performing worse in several respects like applicability, durability and gloss. On the other hand, some acrylate water-based paint were developed for their superior quality on specific materials.[87] Also these paints, however, implied particular tradeoffs in terms of other design criteria like applicability. The occurrence of such tradeoffs is due to the fact that replacing organic solvent by water is technically difficult.[88]
Solvents play essential roles during the application and drying (film formation) of the paint. If water is used instead of organic solvent, the paint has to be dissoluble in water before application, but, after application, the coating film has to be water-repellent. This causes technical problems. Usually, stabilizers and additives are used that are hydrophilic, which means that they can be dissolved in water. Such hydrophilic substances may create weak spots in the coating film after drying. As a result, water may trickle through the coating film resulting in corrosion or wood rot. To overcome these problems and to improve the quality of water-based, additional research on water-based paints has been initiated.

Research efforts[89]

Until at least the seventies, the development of (new) paints was usually based on trial & error, experience, empirical research and extensive testing.[90] Research groups at the university and the knowledge they generated did not play a prominent role in paint development. Nonetheless, several scientific disciplines, in principle, might offer interesting (fundamental) insights for the formulation of paints. These disciplines include polymer chemistry, materials science, fluids & interfaces, rheology & colloid chemistry and process engineering.[91] Insights from these disciplines, however, cannot be used in a simple way in the formulation of paints.

a Typical for this transition is that paints with a lower VOC content are no longer only developed for special purposes but are seen as (potential) substitution of existing paints. The exact date of this transition is difficult to trace. In the early eighties, articles began to appear in the *Verfkroniek* - the periodical of the VVVF - in which paints with a lower VOC are increasingly present as *alternatives* to existing paints, instead as paints fit for special applications or in specific circumstances.

Typically, chemical graduates from the universities who are employed in the paint industry have acquired little knowledge of paint technology during their study.[92] Designing paints is mainly learned on the job.
Since the late seventies and early eighties, attempts have been undertaken to stimulate fundamental research on paints, which would be relevant for the paint industry. About the same time, the government was introducing so-called Innovative Research Programs (*Innovatieve Onderzoeks Programma's*) or IOPs. These programs should stimulate industry-oriented research at universities and other research centers.
When the IOPs were introduced, the paint manufacturers' branch organization, the VVVF, started arguing for an IOP on paints. The arguments, used by the VVVF, directly related to the development of water-based paints to reduce VOC emissions. It was argued that water-based paints could hardly meet a number of design requirements like good applicability, durability, elasticity and gloss. It was further assumed that more fundamental knowledge of the molecular behavior of water-based paints was required to overcome these problems. Since water-based paints are of a different physical nature from solvent-based paints and are, at least partly, based on different raw materials, much of the existing (empirical) knowledge and experience did not apply to these paints.[93]
The attempts of the VVVF to start an IOP were not completely successful. It was doubted whether enough interest existed in paint research at the universities. Therefore, a kind of preliminary IOP was started: the so-called Research Stimulation Program Paints or the OSV (*Onderzoeks Stimuleringsprogramma Verf*).
In 1984, the OSV was officially established. It consisted of five research projects that started between 1986 and 1987 at the universities of Leiden, Twente, Delft and Eindhoven. Some projects that were carried out fitted in the empirical research tradition of the existing technological regime of paints, while other projects had a more fundamental scientific character. The latter projects aimed at developing new molecular models to understand the behavior of water-based paints.[94]
The research projects were finished between 1989 and 1991. A positive evaluation of the OSV by both the universities and the paint industry followed. Although the research program had no direct impact on the development of water-based paints, new contacts were established among the research laboratories of the two large Dutch paint companies (Akzo and Sigma) and university researchers.[95]
The positive evaluation of the OSV resulted in the start of a real IOP in 1992. By then, the KWS 2000 program had also been formulated. Given the objective of KWS 2000 and the earlier theme of the OSV, it is not amazing that the central theme of the IOP became 'paints with fewer or no solvents.' Also high solids were now included. The IOP Paints consists of sixteen projects and lasts eight years. The program is to stimulate pre-competitive research, which should allow paint companies a basis for the further development of paints. Apart from research on the molecular behavior of paints, also research on production, application and removal of paints is included. Some projects more or less fit in the existing empirical research pattern, while others had a more fundamental scientific character. This time also non-university research groups like TNO Coatings and the *Stichting Hout Research* (Foundation for Wood Research) are subsidized by the IOP.

Alongside with the OSV and the IOP, an increase in paint research and development is discernable. According to a survey, the number of people active in R&D in the Dutch paint regime rose by 60% between 1985 and 1990.[96] In 1995, it was estimated that one out of seven people active in the paint industry was active in research, development and testing activities.[97] Much of the extra research and development effort is related to environmental issues, especially the development of paints with fewer solvents.[98] Moreover, apart from the IOP Paints, several other stimulation programs have subsidized research on, and the development of paints with fewer solvents.[99]
The relations between the universities and especially the larger paint manufacturers have been intensified.[100] However, in contrast to Akzo and Sigma, the smaller paint manufacturers still have little or no interaction with the universities.[101] This does not mean that such smaller companies have not been active in the development of paints with fewer or no solvents. In fact, the percentage of paint manufacturers that produce paints with a lower VOC content has been steadily rising.[102] Most smaller companies seem well able to develop paints with fewer solvents like water-based paints on the basis of the traditional trial & error approach, information from suppliers and experimental research and testing. Nevertheless, the need to spend more money on R&D to develop more environmental sound paints has induced several mergers and takeovers in the paint industry.[103]

Overall, the relation between fundamental research and advances in, for example, water-based paints is somewhat unclear. It seems that the development of new raw materials by chemical suppliers has played a far more important role in the development of water-based paints and other paints with a lower VOC content than the insight in the molecular behavior of such paints.[104] This is surely true for the smaller companies but probably to an important extent also for companies like Akzo and Sigma.[105] Research by universities has thus played some role in the development of alternative paints, but the development of these paints was largely supplier-dependent.

4.2.2 KWS 2000 and the Acceptance of Paints with a Lower VOC Content

In 1989, the Dutch government started the program KWS 2000 to reduce the amount of VOCs in paints. By then, an array of technical alternatives was available. Suppliers had developed new raw materials and research at the Dutch universities had been initiated. Nevertheless, the Dutch government decided to base KWS 2000 on self-regulation by the industry. Why did the government not decide to ban particular VOC-rich paints or to reduce the amount of VOCs in paints by other types of regulatory measures? At the time, some environmental groups indeed believed that the time was ripe for direct governmental regulation. In 1986, the Dutch environmental group *Natuur en Milieu* (Nature & Environment) proposed in a report to ban the use of VOC-rich paints for some applications.[106] The paint manufacturers organized in the VVVF opposed such regulation and emphasized that any striving for VOC reductions would negatively influence their economic position.[107]

The resistance of the VVVF and the decision of the government to refrain - for the time being - from regulation become comprehensible if we take into account two characteristics of the developed alternatives and the existing technological regime.[108]
First, the technological regime of paints is characterized by many different paints for different applications (Table 4.1). Especially in the industrial market, many paints are tailor-made. Even if the required new raw materials are available, fine-tuning alternative paints still requires much R&D and testing efforts.[109] Paint manufacturers have to spend large amounts of money and time on developing new products. Moreover, most small paint manufacturers did not develop alternatives in anticipation of government policy but merely reacted to it.[110] So in 1989, for many (industrial) applications feasible alternatives were not yet available.
Second, paints containing fewer or no VOCs usually have different characteristics than existing paints for the same applications. Even if the overall quality is comparable, paints with no or fewer VOCs imply different tradeoffs between the design criteria. Development of new raw materials and (fundamental) research could not overcome this. The use of paints with a lower VOC content is not simply a matter of substituting one type of paint by another. Often, new application apparatus, techniques and habits had to be developed. The active cooperation of users and applicators of paints was often required, or coordinated efforts had to be undertaken to change users' practices.
So, the government depended on the paint industry and the users of paints for the effective implementation of its reduction goals. In particular, it depended on the branch organization VVVF because this organization had an information monopoly on the structure of the paint industry and on paint technology.[111]
Meanwhile, paint producers and the VVVF depended on the government because it might intervene if it wanted so. When the government was clearly inclined to take some measures, the VVVF gave up its initial resistance to KWS 2000 and chose to cooperate.[112] In this way, the VVVF hoped to be able to influence the formulation and implementation of KWS 2000. The cooperation of the VVVF was welcomed by the government because this would, in the expectation of government officials, ease the implementation of the reduction goals. As a result, KWS 2000 became based on voluntary cooperation between the actors involved (suppliers, paint producers and

Table 4.1 *Indicative Figures of the Number of Companies that are Active and the Number of Products that are Available in the Three Market Segments (Source: Interview Winkelaar and Statistics VVVF).*

	Turnover (in millions of guilders in 1993)	Turnover (in thousands of tons in 1993)	Number of companies active	Number of brands	Number of products
DIY	285	60	10	30-40	1000
Construction	460	90	40-50	60-80	6000
Industry	360	40	80-90	100-120	7000

paint users), but within some limitations formulated by the government.[113]

The degree to which KWS 2000 has been successful, *i.e.* the degree to which paints with fewer or no VOCs have been successfully developed and are adopted by users significantly differs from market segment to market segment. Below I will discuss each of the three major market segments - the do-it-yourself (DIY), the construction and building and the industrial market - in some detail.

The Do-It-Yourself (DIY) Market

Several paints with fewer VOCs are now available for the DIY market.[114] Alternatives include different kinds of water-based paints (acrylate, alkyd and hybrid) and high solids.[115] The market share of the newly developed water-based paints in the DIY market increased from about 0% in 1986 to an estimated 10% in 1992.[116] At the moment, this percentage is stagnating.[117] One reason for this stagnation is the disagreement about the environmental qualities of water-based acrylate paints.

In 1992, an employee of Akzo, Bancken, published a report in which he stated that acrylate paints were as environmentally harmful as traditional solvent-based alkyd paints.[118] According to the report, acrylate paints particularly had negative environmental effects because they required a large amount of a paint remover containing solvents.[119] This and other presuppositions of the Bancken Report have been heavily criticized by several parties, including the environmental group *Natuur & Milieu*, the Dutch environmental Minister Alders, the program bureau of KWS 2000 and the Trading Organization for the Painting Business.[120] Nevertheless, the media attention given to the Bancken Report and the following discussion have raised doubts about the environmental effects of acrylate paints.

The controversy about the environmental effects of water-based acrylate paints is not the only or the main reason for stagnating sales. Environmental concerns play a limited role in the buying behavior of consumers in relation to paints.[121] According to professor Van Raaij of the Erasmus University of Rotterdam, requirements like availability (colors, gloss degrees) and quality (covering power, applicability, durability) and, to a lesser degree, costs play a more important role.[122] Persistent rumors and stories about the lesser quality of water-based paints, therefore, are probably a more important reason that consumers do not buy water-based paints.[123] Another reason for stagnating sales may be that most consumers are unaware of the fact that most paints contain environmental harmful VOCs and that alternatives are available. Most advertisements for paints pay little attention to environmental aspects.[124] The retail trade and wholesale business do not actively promote the use of paints with fewer VOCs.[125] A Dutch eco-label for paints has been developed but was boycotted by the VVVF because it preferred a European (EU) initiative and feared the existence of two eco-labels with (slightly) different criteria.[126] It is expected that the introduction of an EU eco-label will increase the market share of paints with a lower VOC content.[127]

The Construction and Building Market[128]

In the construction and building sector, water-based acrylate paints were initially the main alternatives. Recently, high solids, water-based alkyd and water-based hybrid paints have also come onto the market.

Painters have usually been distrustful about paints with a lower VOC content, especially about water-based (acrylate) paints.[129] This attitude has been fed by circulating stories about the bad quality of these paints. Disadvantages of paints with a lower VOC content that are often mentioned are applicability, esthetics (gloss), durability (wood rot) and removability. Advantages include drying time and environmental impact.[130] Painters are divided among themselves about the relative disadvantages and advantages of paints with a lower VOC content. Some painters, for example, believe that acrylate paints cause wood rot, while others believe that wood rot is prevented by these paints.[131]

Paints with a lower VOC content are not yet commonly used in the construction and building sector. The estimated market share of non-wall low organic solvent paints is 10-15%.[132] This low market share is often attributed to the (supposed) conservatism of painters. However, such an explanation is insufficient. Painters only have a limited influence on the choice of paints.[133] While some customers consciously choose paints with a lower VOC content, painters usually first have to convince their customers.[134] Reasons for customers not to choose low organic solvent paints are, apart from ignorance, the difference in gloss, the weather-dependent applicability and the fact that some painting companies do not want to give the same guarantees as for traditional alkyd paints.[135]

The larger painting firms working on a national scale have shown less reluctance to switch to low organic solvent paints than their smaller counterparts.[136] They serve large customers that are more interested in costs per square meter than in aesthetic qualities.[137] Moreover, these large painting firms have more time available for the training of painters (the new paints require different application habits) than the smaller companies.

Like in the DIY sector, the sale of paints with a lower VOC content is stagnating. Some customers have argued that painting companies and paint manufacturers should first improve their products and guarantees to make existing alternatives 'real alternatives.'[138] Paint manufacturers, on the other hand, have argued that improved paints with fewer solvents have already been developed.[139] Currently, each actor involved seems to be waiting for the others to take the next step.

The Industrial Market

In the industrial market, many products are tailor-made. Therefore, the switch to low organic solvent paints usually requires cooperation between the paint manufacturer, the industrial client, the supplier of binding agents and the supplier of the application apparatus. All four parties may be involved in the development of new paints and, if necessary, new application apparatus. Often, only two of the listed parties are involved in achieving the actual required innovations.[140]

For tailor-made products, the switch to paints with a lower VOC content implies a huge effort.[141] According to Doorgeest of TNO Coatings, a medium-sized producer of industrial paints has about a hundred customers and delivers about a thousand

products, 90% of which are solvent-based.[142] Since medium-sized companies do not usually have more than ten to twenty R&D workers, it will take years before all paints have been replaced by products with fewer or no VOCs. Moreover, the producers of industrial paints are occasionally confronted with the problem that the required binding agents for newly developed tailor-made products are suddenly not available anymore.
Industrial paints with a lower VOC content often require not only new binding agents and new additives but also changes in application apparatus, application techniques and habits of the applicators. Often, the paint can no longer be suited to the (existing) application apparatus. Instead, the application apparatus should be adapted to the new paints.[143] Take, for example, the switch to water-based paints for electrostatic spraying. In this application method, very small paint particles are electrically charged and directed toward the article to be painted, which is at earth potential and thus attracts the paint particles. If water-based paints are used, the conductivity of the water in the paints becomes a problem. If no special measures are taken (isolation of the apparatus), the applicator may be electrocuted. Other required changes in application are related to the fact that water-based paints are corrosive and the fact that the drying process is different from traditional paints.[144]

The success of the introduction of paints with fewer or no VOCs significantly differs from industrial market (niche) to industrial market (niche). For construction steel, for example, paints with few VOCs were already used before the process of transformation toward paints with a lower VOC content started.[145] In other cases, the use of paints with a lower VOC content is more recent. In still other industrial markets, the switch to low organic solvent paints has hardly been successful until now. An example of the latter is wooden furniture industry. Producers of wooden furniture are usually small or medium-sized local companies. So are the paint manufacturers producing paints for these companies. Relations between furniture producer and paint manufacturer are often old and firm.[146] As with painters, the conservatism of the furniture producers is often held to be one of the reasons for the slow introduction of paints with a lower VOC content. Again, it is doubtful whether this explanation is sufficient.[147]
The use of paints with a lower VOC content requires major revisions in the wooden furniture producer’s production process.[148] Today most furniture is coated after assemblage. If the wooden parts would be coated before they are assembled, high solids without VOCs could be used. This would require a change in the production process of furniture and, therefore, require investments in production apparatus. This would also result in furniture with different aesthetic qualities.[149] For example, pieces of furniture with a rounded, ‘classical’ shape would become more difficult to produce. Since wooden furniture producers (partly) depend on their customers for the acceptance of such different types of furniture, fear of losing market share may discourage them to switch to low organic solvent paints.[150]
Another reason for the difficult introduction of paints with a lower VOC content is the small scale of the wooden furniture industry compared with other paint-consuming industrial sectors like the car industry. Wooden furniture producers and the paint manufacturers supplying them are much less substantial than their

counterparts in the car industry. Therefore, fewer resources are available to develop and switch to new paints and application apparatus. Also the producers of binding agents are more interested in developing new binding agents for new car paints than for new wooden furniture paints.[151] All these factors constrain the development and acceptance of paints with a lower VOC content in the wooden furniture industry.

4.2.3 Transformation of the Technological Regime of Paints

The process of transformation, described in the preceding sections, has resulted in the development of paints with a lower VOC content. The development of these paints was enabled by the proactive development of new binding agents and other raw materials by chemical suppliers and spurred by impending governmental regulation and the program KWS 2000.

According to a VVVF survey, paints with a lower VOC content now have an overall market share between 15% and 20% in the Netherlands.[152] The VVVF believes that for particular applications, the use of paints with a high VOC content will continue.[153] Feasible alternatives are not believed to be, or to become, available. In 1995, the VVVF estimated that VOC emissions related to paints had been reduced by 20% till 30%, as compared with 1981.[154] So, it may be doubted whether the reduction goal of 50% in 2000 will be reached.

Within the technological regime of paints, the development of paints with a lower VOC content is now generally accepted. This change is part of a broader process of transformation. In this process, environmental sustainability is increasingly becoming important as design criterion in the technological regime of paints. This transformation is exemplified by the introduction of environmental management systems in the paint industry, and the adoption of responsible care as corporate code.[155] Although both changes are not specific to the paint regime, they have contributed to making environmental sustainability a more legitimate and integral design criterion in the formulation of paints.

Growing environmental concerns and discussions about environmental regulation have resulted in a somewhat changed relationship between especially the VVVF and the government.[156] Since the eighties, the relation between the VVVF and the government has become more intimate and based on mutual understanding. Before, the VVVF tried to keep the government as far away as possible. Now, the Dutch government and the VVVF jointly assess how particular environmental goals can be reached. Typically, the closer contacts between government and industry (VVVF) implied that negotiations about environmental measures were removed from the public sphere.

Relations between the paint industry and initial outsiders like environmental groups have little changed.[157] Environmental groups are hardly involved in the formulation and implementation of environmental policy measures in relation to paints. Contacts between paint firms and environmental groups have not increased.

A number of transformations have taken place in the technological regime of paints that increase the capacity of paint producers to develop alternative paints meeting environmental criteria. Due to the striving for more environmentally sound paints in general and paints with a lower VOC content in particular, R&D efforts in the paint industry have increased. Increasingly, tools as environment Life-Cycle Analysis (LCA) are used to make assessments for future R&D.[158]

Contacts between the larger Dutch paint companies and Dutch universities have multiplied. Although this seems not to have contributed to paint innovation in a direct way, it may open new possibilities for the future and it may, in the event, lead to more radical innovation. Finally, paint producers increasingly do not wait for suppliers to take an initiative in developing new raw materials, but ask their suppliers for specific products with specific characteristics.[159]

Although research has become more important and paint companies have increased their R&D efforts, the innovation pattern remained supplier-dependent. This also implies that the development of technical alternatives not meeting the R&D trajectories of suppliers is constrained. This becomes clear if one looks at the development of so-called natural paints.

The development of natural paints started in the late seventies by people who were concerned about the growing use of synthetic materials in paints and the depletion of natural resources.[160] In Western Europe, the first initiatives were undertaken in Germany. These initiatives were subsequently followed in countries like the Netherlands. In time, several natural paint producers have been established.

The formulation (design) and production of natural paints is based on a number of principles, that together amount to the new guiding principle ‘soft chemistry.’[161] This guiding principle has been translated into more specific criteria for paints. In practice, the formulation of natural paints has mainly focused on the use of resources produced by photosynthesis.[162] This avoids the depletion of fossil fuels. Moreover, resources produced by photosynthesis can be regenerated, are easily degradable and are usually not toxic.

Over the years, natural paints have acquired a small market share, less than 1%. Natural paints have several technical disadvantages and their availability is limited. They have also been criticized for environmental reasons. Natural paints contain terpentine. This solvent is reported to contribute to smog formation.[163] Despite their present (environmental) disadvantages, natural paints seem to represent a potential solution to a number of environmental problems with which the paint industry will be confronted in the future like the use of (toxic) biocides and additives and the depletion of fossil resources.[164]

Improving the (environmental) performance of natural paints will require extra R&D efforts. Natural paint producers lack the resources for such R&D. The existing supplier-dependent innovation pattern is especially constraining in this respect. Most raw materials used in natural paints are not delivered by the chemical industry. So, natural paint producers cannot profit from R&D on, and innovations in raw materials like other paint producers can. It is not very likely that the development of raw materials for natural paints will become a research subject for chemical suppliers in the near future, because the formulation of natural paints is based on principles that radically differ from those on which the existing chemical industry is based.

4.3 Discussion and Conclusion

In both cases studied in this chapter, existing technological regimes were transformed. Existing component parts of household refrigerators and paints were replaced by others, changing the technical configuration of these technologies. New design criteria and requirements related to environmental sustainability became (more) important, changing the definition of functions to be fulfilled in both regimes. So, in both cases new alignments between technical configurations and functions were brought about. By that, the existing trajectories of technological development were changed. These changes can be summarized by saying that environmental sustainability has become a more important design criterion.

In both cases, outsiders like critical scientists and environmental groups played an important role in initiating the sketched transformations by making the aggression of the existing technological regimes manifest. Scientists were crucial for the discovery of particular harmful secondary effects of household refrigerators and paints like the degradation of the ozone layer due to CFCs, and smog formation due to VOCs. Societal groups played a crucial role in making these secondary effects visible to the public. In this way, they helped to place these issues on the public and political agenda. More specifically, societal groups delegitimized the (outcomes of the) existing technological regimes. As a result of this delegitimation, governments felt forced to intervene in the existing regimes in order to substitute particular environmentally harmful substances (CFCs, VOCs) by more environmentally sound ones.

Governmental interference was in both cases enabled by the availability of technical alternatives, which was in turn due to the proactive R&D and innovation policy of suppliers. In the case of refrigerators, this enabled governments to ban CFCs. In the case of paints, the government opted for self-regulation by industry because alternatives were not available for all applications. Much R&D, testing and fine-tuning efforts would still be required. Moreover, existing alternatives brought tradeoffs for users that were not easily accepted by them and that sometimes required changes in users' behavior and investments in application apparatus and production lines. So, the active cooperation of paint producers and users was required.

While outsiders were crucial in initiating the studied processes of transformation, they hardly played a role in the remainder of the process. (An exception is the second part of the refrigerator story that I will discuss in more detail below). What happened was that societal groups created a situation in which particular regime insiders, like governments, began to aim at a transformation of the existing technological regime. This effectuated the route of regulation. Via this route, particular secondary effects were fed back to the existing technological regime and translated into the new design criterion of environmental sustainability.

Apart from governments, branch and professional organizations like the IIR, the ZVEI and the VVVF played an important role in the processes of transformation. The IIR was an important forum in which such issues as the consequences of ozone degradation due to CFCs for refrigeration design were debated. Similar roles were played by the ZVEI and VVVF. They functioned as fora for processes of technical agenda building in which the central elements of the technological regime were redefined.

A crucial role in the redefinition of the central elements of the technological regimes was also played by suppliers. They proactively developed new component parts, even before other elements of the technological regimes were reformulated or changed. This role of suppliers, which is typical for a supplier-dependent innovation pattern, both enabled and constrained the studied process of transformation. It enabled the processes of transformation because suppliers proactively undertook R&D and proactively developed alternative component parts or raw materials. Suppliers did so in the expectation that sooner or later the government might intervene if particular secondary effects would not be taken away. By proactively developing new products or raw materials, suppliers, intentionally or not, enabled actual governmental interference. So, they helped to make the expectation on the basis of which they acted come true.

In both cases we saw how professional and branch organizations like the IIR, the ZVEI and the VVVF initially opposed governmental interference, but later were to accept it to some degree. They did so partly because the active acceptance of some form of regulation offered them the possibility to influence the further course of affairs. The strategies of these branch and professional organizations were related to their position in the technological regime. As ‘private interest governments,’ they kept an eye on the long-term interests and viability of the regime as a whole. This made them more willing to accept the need of particular transformations than most individual designer/producers. Moreover, to stay credible as representative of their members vis-à-vis the government, they had to give in to governments.

Governments were prepared to cooperate with organizations like the ZVEI and the VVVF because they had something to win in terms of the effectiveness and costs of the implementation of specific measures. As a result, governments aimed at self-regulation by industry (paints) or allowed alternatives to CFCs that might not be optimal from an environmental point of view, but were accepted by industry (refrigerators).

By committing themselves to particular policy objectives, branch organizations came into a position in which they began to strive for particular transformations of the existing technological regime. Sometimes, they opted for such transformations even if this was against the (short-term) interests of some of their members.[165] As an official of the VVVF has expressed it in regard of the implementation of environmental management systems in the paint industry:

> *[T]he VVVF protects the interest of the sector. Therefore, we have to guide the sector, sometimes even against the will of its members. Companies which neglect the introduction of an environmental management system can cause negative publicity and damage the (economic) interests of the sector.*[166]

By the actions of branch organizations, then, individual designer/producers were maneuvered into a position in which it was harder for them to resist particular transformations.

The above shows how the proactive R&D and innovation policy of suppliers enables subsequent steps, which create a situation in which it becomes more likely that other actors - preeminently governments, branch organizations and designer/producers - begin to support particular transformations in a technological regime. This dynamics may also work if governments do not actually interfere in a technological regime. In that case, the desire to avoid governmental interference may motivate regime insiders, especially those active at the global level, to aim at particular transformations that take away the undesirable secondary effects.
The important point is that in all such cases the supplier-dependent innovation pattern is enabling in roughly the same way: suppliers proactively develop particular technological alternatives or new component parts that enable further steps leading to the actual transformation of a technological regime.

The fact that suppliers take the initiative in developing technical alternatives in a supplier-dependent innovation pattern also constrains processes of transformation. As we have seen in the refrigerator case, it may result in a lock-in. One reason why a lock-in occurred here was that the chemical industry could put forward one alternative, HFC 134a, as *the* alternative to CFC 12. The fact that this alternative was supported by the chemical industry as supplier of the refrigerator firms gave this alternative already a competitive advantage over other alternatives, even apart from the specific technological characteristics of the product. This advantage was so great that the disadvantages of HFC 134a for refrigerator firms and governments were eventually traded away. Governments and refrigerator firms jumped the HFC 134a bandwagon, by that enlarging the competitive advantage of HFC 134a.
In the paint case, no lock-in in a specific product was created. This is related to initial differences between the regime of household refrigerators and that of paints. The paint regime was characterized by a large array of paints for different applications; many of these paints were tailor-made. Due to the broad variety of paints and their application-specificness, a lock-in - in the sense that *one* alternative became dominant - was not and could not be created. Still, we can speak of a lock-in in the trajectory of synthetic paints. The development of natural paints was constrained because these paints are not (commercially) interesting for chemical suppliers and do not fit their existing R&D capabilities and trajectories. Therefore, less R&D capacity is available to develop and optimize natural paints.
The constraints for the development of technical alternatives inherent in the supplier-dependent innovation pattern meant that such alternatives as the *Greenfreeze* and natural paints had to be developed independent of the existing technological regimes. These technical alternatives were developed in protected spaces created by actors who were outside the existing technological regime or played only a marginal role in it.[167]
As the *Greenfreeze* story shows, technical alternatives developed in protected spaces can play an important role in transforming a technological regime. In this case, the *Greenfreeze* was effectively used to mobilize users against the technological regime of household refrigerators. In a brief period, the *Greenfreeze* became so popular that the other refrigerator producers, fearing a loss of market share, decided to switch to

Greenfreeze technology. The *Greenfreeze* became the exemplar of a new type of refrigerator, a refrigerator with hydrocarbons as coolant.[168]
The *Greenfreeze* story shows a second route for the feedback of particular secondary effects to a technology regime. This is the route of user pressure, a route that hardly played a role in the paint story. One might wonder why. The explanation can be found in the performance disadvantages that alternative paints bring for consumers. Consumers of refrigerators could opt for a *Greenfreeze* without giving up something in terms of the performance of the refrigerator or having to change habits. In return to buying a *Greenfreeze*, they received a normally operating refrigerator and a 'good feeling.' Consumers of paints may also get a 'good feeling' by using paints with a lower VOC content, but they have to accept new tradeoffs in terms of paint performance and have to change habits, which only some of them found acceptable.

Notes to Chapter 4

1 This case study is based on empirical research carried out by author and Hugo Verheul, who is at the University of Delft, the Netherlands. Part of this research was financed by the SEER program of the European Community (DG XII). I would also like to thank José Andringa and B. Wynne for providing materials on this case. Parts of the case description were earlier published in I. van de Poel & C. Disco, 'Influencing Technology; Design Worlds and Their Legitimacy,' in J. Perrin & D. Vinck (eds.), *The Role of Design in the Shaping of Technology* (Proceedings from the COST A3 and COST A4 workshop Lyon, France, 3 and 4 February 1995) (Luxembourg: Office for Official Publications of the European Communities, 1996), 93-130 and in I. van de Poel, 'Who Formulates the Design Requirements?,' paper presented at the Joint 4S/EASST Conference, 10-13 October 1996 in Bielefeld, Germany.
A short description of the case can also be found in H. Verheul & Ph.J. Vertragt, 'Social Experiments in the Development of Environmental Technology; A Bottom-up Perspective,' *Technology Analysis & Strategic Management*, 7(1995)3, 315-326 and in H. Verheul. & I. van de Poel (1995), 'Koolwaterstoffen als koudemiddel: een analyse van de doorbraak,' *RCC koude & luchtbehandeling*, 88(1995)2, 17-18 (in Dutch).
I have made use of case descriptions of Hugo Verheul and José Andringa (J.M. Andringa, 'De vervanging van CFK's door propaan/butaan in koelvloeistoffen van huishoudkoelkasten in Nederland: Argumenten en posities van actoren' (1994), Mimeo, 25 pp., paper ter afronding van het vak "Sturingsprojecten"; H. Verheul, 'Case Report Greenfreeze' (no date), Mimeo, 10 pp).

2 The description below on the ozone issue and the reaction of the chemical industry is mainly based on a special issue of *AMBIO A Journal of the Human Environment*, XIX(1990); National Wildlife Foundation (1989), 'Du Pont Freon Products Division,' case study prepared by Foest Reinhardt and *The News Journal*, August 25-28 1991, Reprint.

3 D.J. Dudek, A.M. LeBlanc & K. Sewall, 'Cutting the Cost of Environmental Policy: Lessons from Business Response to CFC Regulation,' *AMBIO A Journal of the Human Environment*, XIX(1990)6-7, 324-328.

4 According to some critics, such industry-funded research have tended to play down the damage of CFCs to the ozone layer. These critics argue that ozone depletion was not taken fully serious scientifically until the discovery of the hole in the ozone layer in 1985 and the appearance in 1988 of an independent study, headed by Rowland, which showed that ozone depletion had already occurred. It is hard to say whether industry-funded research intentionally played down evidence of ozone depletion. Typically, the studies showing no ozone depletion were mainly done by statisticians and not by chemists or atmospheric scientists. An important reason why these studies did not show ozone depletion was that measurements of possible ozone depletion were made during summer, assuming that there was no difference between possible ozone depletion during summer and during winter. Scientists now know that ozone depletion usually occurs during winter. Whatever the motives of early industry-funded

researchers, by the late eighties a firm scientific consensus was growing that ozone depletion was occurring and had indeed already occurred (*News Journal*, Special Reprint Edition, August 25-28, 1991, 6.).

5 *The News Journal*, August 25-28 1991, Reprint, 6 and 12.

6 *Ibid.*, 6.

7 *Ibid.*, 7.

8 In 1988, Du Pont produced 25% of the world's CFCs and 50% of them in the USA. In 1987, its Freon Product Division, responsible for the production of CFCs, had eleven CFC factories over the world employing 1200 people. The sales of CFC amounted to 2% of the incomes of Du Pont. (National Wildlife Foundation, *Op. cit.*; *The News Journal*, August 25-28 1991, Reprint, 9).

9 *Ibid.*, 6-7.

10 *Ibid*; National Wildlife Foundation, *Op. cit.*.

11 C.A. Moore, 'Industry Responses to the Montreal Protocol,' *AMBIO A Journal of the Human Environment*, XIX(1990)6-7, 320-323 cites Hoechst supporting a phase-out of CFCs by 1995 and other firms like Du Pont and ICI a phase-out by 2000.

12 *Cf.* National Wildlife Foundation, *Op. cit.*; Dudek *et al., Op.*; Moore, *Op. cit.* and *News Journal*, Special Reprint Edition, August 25-28, 1991.

13 *News Journal*, Special Reprint Edition, August 25-28, 1991, 7-8.

14 At the end of the seventies Du Pont spent between the 3 and 4 million dollars on research on alternatives to CFCs (National Wildlife Foundation, *Op. cit.*).

15 National Wildlife Foundation, *Op. cit.*, 12. See also Dudek *et al.*, *Op. cit.*, 326.

16 *News Journal*, Special Reprint Edition, August 25-28, 1991, 9.

17 L.J.M. Kuijpers, 'Conference Review: Copenhagen 1992; A Revision or a Landmark?,' *International Journal of Refrigeration*, 16(1993)3, 210-220; *International Journal of Refrigeration*, 13(1990)6, 349; *Koude & Lucht* 86(1993)7, 14.

18 The analysis below on how the ozone issues was discussed in the refrigeration regime is based on editorials and the rubric 'IIR News' in the *International Journal of Refrigeration*, the international journal for the heating, ventilating, air-conditioning and refrigeration industry, and science. See *International Journal of Refrigeration*, 9(1986)7, 195; 10(1987)3, 127; 10(1987)7, 187; 10(1987)11, 316-317; 11(1988)1,3; 11(1988)3, 105-106; 11(1988)3, 131; 12(1989)7, 179; 12(1989)9, 244-245; 13(1990)3, 59; 13(1990)7, 211; 13(1990)7, 212-213; 13(1990)9, 284; 13(1990)11, 347; 13(1990011, 349-350; 14(1991)3, 67; 14(1991)3, 68-69; 14(1991)3, 124; 14(1991)7, 189; 15(1992)2, 67-68; 15(1992)5, 261-262; 15(1992)6, 323-325; 16(1993)1, 3. See further Kuijpers, *Op. cit.* and A.L. Stolk, 'The Need to Curb CFC Emissions,' *International Journal of Refrigeration*, 10(1987)5, 271-275.

19 National Wildlife Foundation, *Op. cit.*.

20 *International Journal of Refrigeration*, 9(1986)4, 195

21 These points can be found in a statement of the IIR just before the Montreal Conference. See: *International Journal of Refrigeration*, 11(1988)3, 105.

22 *International Journal of Refrigeration*, 12(1989)5, 244.

23 Especially the update of the Montreal Protocol in 1990 in London made the reduction of CFCs used in refrigerators inescapable. As IIR director Gac notes: '[T]he restrictions which have just been decided touch directly and almost exclusively on the refrigerating, air-conditioning and heat pump industries. Hence, London is a turning point for these industries.' (*International Journal of Refrigeration*, 13(1990)6, 349). See further: Kuijpers, *Op. cit.* and *Koude & Luchtbehandeling*, 86(1993)7, 14.

24This section is mainly based on J.L. Boot, 'Overview of Alternatives to CFCs for Domestic Refrigerators and Freezers,' *International Journal of Refrigeration*, 13(1990)2, 100-105; J.S. Hoffman, 'Replacing CFCs: The Search for Alternatives,' *AMBIO A Journal of the Human Environment*, XIX(1990)6-7, 329-333; W.L. Kopko, 'Beyond CFCs: Extending the Search for New Refrigerants,' *International Journal of Refrigeration*, 13(1990)2, 79-85; H. Kruse, 'CFC Research Programmes in Western Europe,' *International Journal of Refrigeration*, 13(1990)2 , 122-130; Kuijpers, *Op. cit. 1993*; L.J.M. Kuijpers, 'UNEP Assessment of the Montreal Protocol: Refrigeration within the Framework of the Technology Review,' *International Journal of Refrigeration*, 13(1990)2 , 95-99; L. Kuijpers & S.M. Miner, 'The CFC Issue and the CFC Forum at the 1988 Purdue IIR Conference,' *International Journal of Refrigeration*, 12(1989)3, 118-124; E. Preisegger & R. Henrici, 'Refrigerant 134a: The first Step into a New Age of Refrigerants,' *International Journal of Refrigeration*, 15(1992)6, 326-331; H.O. Spauschus, 'Compatibility Requirements for CFC Alternatives,' *International Journal of Refrigeration*, 13(1990)2 , 73-77; Stolk, *Op. cit.*; S. Östlund & R. Larsson, 'The Greening of Strategic Alliances' (1991), Paper to be presented at The 11th Annual International Conference, Strategic Management Society, Toronto Canada, October 23-26, 1991;*International Journal of Refrigeration* 11(1988)9, 344, 11(1988)11, 393, 12(1989)9, 302-303, *Koude & Klimaat*, 83(1990)1, 14-17 and 83(1990)2, 9-11; S. Cohen & A. Pickaver (eds.), *Climbing Out of the Ozone Hole* (Greenpeace International, 1992); Greenpeace, *Der FCKW-Ausstieg ist möglich. Sofort!; Praktische Alternative zur FCKW* (Hamburg: Greenpeace, 1992); Interview Lotz, 12-5-1994.

25 In 1977, the DKV - the professional organization of German refrigeration engineers - organized a meeting on the ozone issue. At this meeting, it was decided to postpone action until there was more consensus about the ozone issue among experts. In the mid eighties, individual refrigerator firms began to research alternatives to CFC 12 in their own labs (Interview Lotz, 12-5-1994).

26 Interview Lotz, 12-5-1994. Also in the USA, such a common initiative was undertaken. Refrigerator and freezer manufacturers formed the *Appliance Industry-Government CFC Replacement Consortium*.

27 *International Journal of Refrigeration*, 11(1988)9, 344-345; *Koude Magazine*, May 1992, 10-11; *Koude & Klimaat*, 83(1990)1, 14-17.

28 *Cf. Koude Magazine*, August 1992, 15-17; *Koude & Klimaat*, 83(1990)1, 14-17 and 83(1990)2, 9-11; Preisegger & Henrici, *Op. cit.*.

29 Interview Lotz, 12-5-1994.

30 *Ibid.*; Kruse, *Op. cit.*, 126.

31 Chemical firms like Du Pont en ICI have actively developed new lubricants for HFC 134a . The decision of the German refrigerator firms to choose HFC 134a was especially inspired by the decision of the automobile industry, which was a major market for refrigerants, to opt for HFC 134a as alternative coolant for car air-conditioning (Interview Lotz, 12-5-1994).

32 *International Journal of Refrigeration*, 15(1992)6, 323.

33 Kuijpers & Miner, *Op. cit.*. Also some Dutch refrigeration engineers has questioned the choice for HFC 134a. See, for example, *Volkskrant* 27-8-1992.

34 *Cf.* Hoffman, *Op. cit.,* 331.

35 Also in Dutch magazines on refrigeration like *Koude Magazine* and *Koude & Klimaat* attention is being paid to these coolants.

36 *International Journal of Refrigeration*, 13(1990)5, 283; Boot, *Op. cit.*; Kopko, *Op. cit.*.

37 *Koude Magazine*, August 1992, 12-14; Ree, C.M. (1992), 'De vervanging van CFK's door HFK's als koelvloeistoffen; Produktieprocessen van HFK's' (Notitie in opdracht van de Zuidhollandse Milieufederatie n.a.v. de voorgenomen produktie van HFK-134a bij Du Pont de Nemours Nederland B.V. te Dordrecht), Mimeo, 10 pp; Letter Greenpeace to *College van Gedeputeerde Staten van Zuid-Holland*, 20-5-1992.

38 *News Journal*, Special Reprint Edition, August 25-28, 1991, 10.

39 *Ibid.* and *Koude Magazine*, August 1992, 12-14. Professor Reijnders of *Natuur & Milieu* claims HFC 152a to be more energy efficient than 134a. He thinks the resistance to HFC 152a is due to its flammability and the fact that is not easy to patent for the chemical industry and relatively cheap. Hoffman, *Op. cit.* cites research results that point to HFC 152a being more energy efficient than HFC 134a.

40 *News Journal*, Special Reprint Edition, August 25-28, 1991, 10.

41 In 1990, Bauknecht published a report on propane as coolant. It appeared that a spark was enough to cause a (very) small explosion. For that reason, Bauknecht abandoned propane as an alternative (*NRC-Handelsblad*, 18-8-1992).

42 *Cf.* Östlund & Larsson, *Op. cit.*.

43 David R. Tree, 'Editorial,' *International Journal of Refrigeration*, 13(1990)4, p. 211.

44 Preisegger & Henrici, *Op. cit.*.

45 This section is based on Anonymus, 'Greenpeace Weans Industry from Ozone Destroying Chemicals,' *Greenpeace Campaign Report*, (1993)14; Anonymus, 'Refrigeration Revolution Spreads as Ozone Crisis Deepens,' *Greenpeace Campaign Report*, (1993)15; Anonymus, 'Treuhand Move Stalls Eco-friendly Fridge,' *Chemistry & Industry*, 3 August 1992, 549; J. Conrad, 'Greenfreeze: Environmental Success by Accident and Strategic Action,' in M. Jänicke & H. Weidner (eds.), *Successful Environmental Policy; A Critical Evaluation of 24 Cases* (Berlin: Wissenschaftszentrum für Sozialforschung, 1995), 364-378; K. Craggs, 'The Fridge-maker Who Came in from the Cold,' *International Management*, October 1992, 28; K. Daey Ouwens & E. Sjoerdsma, 'Prima koelen met propaan,' *Natuur en Milieu*, February 1993, 4-7; Greenpeace, De Greenfreeze; De eerste ozonveilige koelkast (Amsterdam: Greenpeace, 1993), Mimeo, 8 pp.; Greenpeace, The "Greenfreeze" Story; The Development of Atmosphere Safe Refrigerators Without Ozone Depleting CFCs, HCFCs or Global Warming HFC chemicals (Washington: Greenpeace, 1993), Mimeo, 6 pp.; Greenpeace, Saving the Ozone Layer with Greenfreeze; The Greenpeace Guide to Fridges (London: Greenpeace, no date), Mimeo, 14 pp.; Greenpeace, Greenfreeze; A Revolution in Domestic Refrigeration (1996), Document retrieved from the WWW on 7-5-1996, http://www.greenpeace.org/~ozone/greenfreeze/index.html, 6 pp.; International Institute of Refrigeration (ed.), *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (Proceedings of the meeting of International Institute of Refrigeration Commission B2, May 10-13, 1994, Hannover, Germany) (Paris: IIR, 1994), M. Smeitink, 'De groene koelkast rukt op,' *Greenpeace*, (1994)1 , 4; F.J. Stouthart, ''Groen koelen' met propaan en butaan,' *Koude Magazine*, March 1993, 13-15; T. Toro, 'German Industry Freezes out Green Fridges,' *New Scientist*, 135(1992)1835 , 16; J. Vidal, 'The Big Chill,' *The Guardian*, 19 November 1992, 2-3; Interview Heslop, May 1994; Interview Günther, May 1994; Interview Lotz, 12-5-1994; Interview Representative Danfoss, May 1994; information from dr. Rosin.

46 Before, Dr. Rosin first was at the University Institute of Medical Microbiology at Düsseldorf, where he started thinking about developing an environmentally friendly coolant in 1988. Rosin and Preisendanz objected to HFCs like HFC 134a not only because they contributed to the greenhouse effect, but also because they were concerned about possible chemical reactions HFCs might cause in the atmosphere, producing poisonous substances and acids.

47 At that moment, Greenpeace was already active in the ozone debate for a long time, and at least in twelve different countries. It the 1980s, Greenpeace had lobbied for a phase-out of CFCs. Later, it had concentrated on the development of desirable alternatives. Attention then moved from public and political debate toward the user industry.

48 Greenpeace, The "Greenfreeze" Story; The Development of Atmosphere Safe Refrigerators Without Ozone Depleting CFCs, HCFCs or Global Warming HFC Chemicals (Washington: Greenpeace, 1993), Mimeo, 6 pp.; R.B.J. Kemna, 'Notitie koelkastmarkt t.b.v. het Wereldnatuurfonds' (1992), rapport Van Holsteijn en Kemna, 6. These were tests carried out under ISO 8187 conditions.

49 There were some other tests suggesting that a refrigerator with hydrocarbons might be more energy efficient. These tests were, however, not officially carried out under ISO 8187 conditions (Kemna, *Op. cit.*).

50 R.W. James & J.F. Missenden, 'The Use of Propane in Domestic Refrigerators,' *International Journal of Refrigeration*, 15(1992)2, 95-99.

51 Interview Lotz, 12-5-1994.

52 Conrad, *Op. cit.*.

53 Interview Günther, May 1994.

54 To a lesser extent, this is also true for a mixture of two gases. Using only one coolant, isobutane for example, required, however, more adaptations in the compressor. Adaptations that were difficult to achieve for DKK. Later, when the difficulties with the compressor could be solved, DKK switched to isobutane as refrigerant (*Cf.* E. Günther, 'Hydrocarbons as Refrigerants in Domestic Refrigerators,' in International Institute of Refrigeration (ed.), *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (Proceedings of the

meeting of International Institute of Refrigeration Commission B2, May 10-13, 1994, Hannover, Germany) (Paris: IIR, 1994), 37-48).

55 *Cf.* Interview Günther, May 1994; E. Bodio, M. Chorowski & M. Wilczek, 'Working parameters of domestic refrigerators filled with propane-butane mixture,' *International Journal of Refrigeration*, 16(1993)5, 353-356; G. Lorentzen, 'Use of Natural Refrigerants. A Complete Solution to the CFC/HCFC Predicament,' in International Institute of Refrigeration (ed.), *New applications of natural working fluids in refrigeration and air conditioning* (Proceedings of the meeting of International Institute of Refrigeration Commission B2, May 10-13, 1994, Hannover, Germany) (Paris: IIR, 1994), 23-36.

56 Minor changes in the refrigerator circulation circuit, especially the vaporizer and capillaries, were required (Günther, *Op. cit.*, 41). Later, DKK switched to isobutane as coolant. This switch required adaptations in the compressor that was DKK not yet able to make in 1992 (Günther, *Op. cit.*, 42).

57 Conrad, *Op. cit.*, 369.

58 Interview Günther, May 1994; Conrad, *Op. cit.*. In July 1992, the ZVEI already had sent a 'voluntary commitment' to the German Minister of Environment, from which DKK Scharfenstein was excluded. Also the German chemical firm Hoechst tried to blacken DKK and the *Greenfreeze* by arguing that its energy consumption was too high (Conrad, *Op. cit.*, 370),

59 Interview Günther, May 1994.

60 Interview Danfoss, May 1994.

61 H. Jürgensen, 'Application of Hydrocarbons as Refrigerant in Household Refrigerators,' in International Institute of Refrigeration (ed.), *New applications of natural working fluids in refrigeration and air conditioning* (Proceedings of the meeting of International Institute of Refrigeration Commission B2, May 10-13, 1994, Hannover, Germany) (Paris: IIR, 1994), 589-594. Quote from page 594.

62 *Greenpeace*, (1994)1, 4. For 1996, a market share of more than 80% is expected.

63 Anonymus, 'China plans "Greenfreeze" production,' *Greenpeace Business*, December 1993, 2; Greenpeace, 'The refrigerator revolution; Hydrocarbons: the right choice for China' (Hamburg: Greenpeace, 1993), Mimeo, 8 pp..

64 Greenpeace, *Op. cit. 1996*, 5.

65 Quote from Greenpeace, 'Greenfreeze; A Revolution in Domestic Refrigeration' (1996), document retrieved from the WWW on 7-5-1996; http://www.greenpeace.org/~ozone/greenfreeze/index.html, 6 pp..

66 Interview Lotz, 12-5-1994.

67 For the idea of path dependency and lock-in, see Arthur (1988) and Chapter 2.

68 For an account of how the functioning or properties of (household) products may be made invisible to the consumers and how an inside and outside for the product are created see Chabaud-Richter (1995).

69 See I. van de Poel, 'Who formulates the design requirements?,' paper presented at the Joint 4S/EASST Conference, 10-13 October 1996 in Bielefeld, Germany.

70 See, for example, *Modern Plastics International*, May 1993, 47-49 and January 1994, 16-20; *Urethanes Technology*, April/May 1993, 6-8 and June/July 1993, 18; 'Hydrocarbons Provide Zero ODP and Zero GWP Insulation for Household Refrigeration,' Liebherr, Mimeo, 18 pp..

71 'Super energiezuinige en milieuvriendelijke koelkast gepresenteerd,' persbericht Provincie Noord-Holland, 7 April 1994; E. Sjoerdsma, 'Het vrijezuiger Stirling Koelsysteem voor lichtnet- en zonnekoelkasten,' Mimeo; T. Maurer, P. Feulner & H. Krauch, 'The Apllication of the Stirling Cycle to Near-Ambient Temperature Refrigeration,' in International Institute of Refrigeration (ed.), *New applications of natural working fluids in refrigeration and air conditioning* (Proceedings of the meeting of International Institute of Refrigeration Commission B2, May 10-13, 1994, Hannover, Germany) (Paris: IIR, 1994), 651-662; B.D. Mennink & D.M. Berchowitz, 'Development of an Improved Stirling Cooler for VSI insulated Domestic Fridges With Thermal Store and Photovoltaic Power Source for Industrialized and Developing Countries,' in International Institute of Refrigeration (ed.), *New applications of natural working fluids in refrigeration and air conditioning* (Proceedings of the meeting of International Institute

of Refrigeration Commission B2, May 10-13, 1994, Hannover, Germany) (Paris: IIR, 1994), 631-640.

72 See E. Homburg, 'Een bedrijfstak in verandering,' in H. Lintsen, *et al.* (ed.), *Geschiedenis van de Techniek in Nederland (Deel IV)* (Zutphen: Walburg, 1993), 259-270, especially pages 265-266 and E. Homburg, 'Industrie, Chemie en Milieu (1750-1815),' in H. Lintsen, *et al.* (ed.), *Geschiedenis van de Techniek in Nederland (Deel IV)* (Zutphen: Walburg, 1993), 159-179, especially pages 174-179.

73 A.P.J. Mol, *The Refinement of production; Ecological modernization theory and the chemical industry* (Utrecht: Van Arkel, 1995), 150. The actual amount was probably ten times as low.

74 Mol, *Op. cit.*. The decision of the VVVF came after strong pressure from a number of large paint companies which wanted to ban mercury in order to avoid (further) negative publicity.

75 *Ibid.*

76 *Ibid.*, 142-143, especially n. 151. See also R.A. van de Peppel, *Naleving van milieurecht; Toepassing van beleidsinstrumenten op de Nederlandse verfindustrie* (Deventer: Kluwer, 1995), Proefschrift Rijksuniversiteit Groningen, 110.

77 Recently, the negative health effects of VOCs in paints have again received more attention.

78 Van de Peppel, *Op. cit.*, 222.

79 Mol, *Op. cit.*, 137; Van de Peppel, *Op. cit.*, 97; Interview Winkelaar, 15-8-1995.

80 The list of design criteria is based on Mol, *Op. cit.*, 133.

81 *Cf.* Mol, *Op. cit.*, 174.

82 Mol, *Op. cit.*, 153-154.

83 The description of these alternatives is mainly based on T. Doorgeest, 'KWS 2000,' *Verfkroniek*, 64(1991)2, 57-62; Programma Voorbereidings Commissie voor het IOP-Verf, *Meerjarenplan voor het IOP-Verf* (Uitgevoerd in opdracht van het Ministerie van Economische Zaken) (Leidschendam: Civi Consultancy, 1991); Mol, *Op. cit.*, 136; U. Zorll & M. Joly, 'Progress in Emission-Free Paint Technology,' in CEPE (ed.), *VOC-Policy of the European Paint Industry* (Presented by CEPE at the first International Congress on Volatile Organic Compounds, March 1991) (Brussel: CEPE, 1991), 10-20. For the developments of new binding agents and new additives see: *Verfkroniek*, 59(1986), 422-426; 65(1992)2, 24-27; 66(1993)12, 19-20; 68(1995)10, 29-33; 69(1996)3, 11-15 and 69(1996)4, 23-28; *Chemisch Weeknlad*, 18 October 1990, 439 and *NCI*, 13 January 1993, 23.

84 Dutch paint manufacturers, for example, developed a number of water-based paints for joinery in the seventies (Interview Peterse, 4-5-1995; and interview De Vries & Huizer, 29-5-1995).

85 *Ingenieurskrant*, (1991)12, 8.

86 S. Meredith & T. Wolters, *Proactive Environmental Strategies in the Paint and Coatings Industry in Great Britain and the Netherlands* (Apeldoorn: TNO, 1994), TNO Report STB/94/022.

87 *Ingenieurskrant*, (1991)12, 8.

88 See references in note 83.

89 This section is mainly based on B. van der Meulen, *Beoordelingsprocessen in Wetenschap (Evaluation processes in Science)* (Delft: Eburon, 1992), Proefschrift Universiteit Twente; Programmacommissie IOP-Verf, *Jaarverslag en jaarwerkplan 1991* ('s-Gravenhage: Programmabureau IOP-Verf, 1991), Mimeo: 19 pp and Programmacommissie OSV, *Evaluatie proefprojecten* (Civi Consultancy, 1989).

90 For more details and references, see the description of the existing technological regime in Appendix 3.

91 Programmacommissie OSV, *Evaluatie proefprojecten* (Civi Consultancy, 1989), 15-16. See also interview Peterse, 4-5-1995.

92 *Eisma's Vakpers*, 97(1996)17, 29-30.

93 Water-based paints are physically significantly different from solvent-based paints because the binding agent is not dissolved in the solvent but dispersed in water. Moreover, they are more complex because they contain far more additives than conventional alkyd paints. A water-based acrylate paint may contain twice as much substances than a 'traditional' solvent-based alkyd paint (*Verfkroniek* 60(1987), 354-357).

94 In the former projects, existing theoretical models were used to develop new empirical knowledge on water-based paints. The latter projects were from a scientific point of view not primarily about paints but about physical chemical systems like emulsion-dispersion systems. Results of these projects, in principle also could be used for other (industrial) applications than paint.

95 *Ingenieurskrant*, (1991)12, 8-9; *Verfkroniek*, 66(1993)2, 24-25; Van der Meulen, *Op. cit.*; Interview Winkelaar, 15-8-1995; Interview Peterse, 4-5-1995; This especially holds for the more 'fundamental' research projects.

96 *Ingenieurskrant*, (1991)12, 8-9 and *Verfkroniek*, 66(1993)2, 24-25. At Sigma, the number of people active in R&D rose from about 150 in 1987 to more than 250 in 1995 (Interview Peterse, 4-5-1995).

97 Interview Winkelaar, 15-8-1995.

98 Sigma, claims that 50-60% of its research is now related to environmental issues. Bancken of AKZO coatings even claims that 80% of Akzo Coatings' R&D budget was directed to environmental-related issues (Interview Peterse, 4-5-1995; Mol, *Op. cit.*, 171-173; *European Chemical News*, 18 November 1991).

99 According to Van de Peppel (*Op. cit.*, 248), paint companies that develop paints with fewer or no VOCs relatively often make use of (research) subsidies.

100 In the early nineties, a postgraduate course in coatings technology was set up by Akzo Coatings, Sigma Coatings and DSM Resins (a major supplier of binding agents in the Netherlands) and the Technical Universities of Eindhoven and Twente. The course lasts five weeks and is given by the companies and the universities together. Since 1 April 1995, the Technical University of Eindhoven has a professor in Coatings Technology. Again, Akzo, Sigma and DSM have played an important role in this initiative. Akzo and Sigma have begun to employ more graduates and doctors, some of which acquired their degrees during OSV or IOP projects, as was indeed more or less a goal of the IOP. (Interview Peterse, 4-5-1995; Interview Bancken and *Eisma's Vakpers*, 97(1996)17, 29-30).

101 Interview De Vries & Huizer, 29-5-1995. Smaller companies often do not employ people with a university grade. This makes it more difficult for them to use insights generated at the universities.

102 Van de Peppel, *Op. cit.*, 264.

103 The market share of large multinational companies is reported to be rising. Moreover, a concentration of the paint industry, through mergers and takeovers, has taken place. Related to this is an increasing internationalization of the paint industry due to the fact the larger multinational companies are better able to bear the required larger R&D costs and to take advantages of economies of scale.
It has been speculated that some of the smaller companies will not be able to 'catch up' with the development of paints with a lower VOC content given the required resources and R&D efforts. In relation - but also partly independent of it - it has been predicted that the market share of smaller companies will decline and that some of them will disappear.
It seems, however, unlikely that all smaller companies will disappear. Some paints are so application-specific that there will probably always remain market niches for the smaller companies. Moreover, due to the growing importance of ecological design criteria, the market for paints has become more dynamic. Smaller companies, with a smaller flexible organization and shorter communication lines, may be better able to react to quick changes in market demand (Mol, *Op. cit.*; Interview Winkelaar, 15-8-1995).

104 Interview De Vries & Huizer, 29-5-1995; Interview Winkelaar, 15-8-1995.

105 Interview Winkelaar, 15-8-1995..

106 A. Klingenberg, *Alternatieven voor organische-oplosmiddelhoudende verf en houtverduurzamingsmiddelen* (Utrecht: Stichting Natuur en Milieu, 1986).

107 Van de Peppel, *Op. cit.*, 241.

108 The reason for the government to opt for self-regulation should also be understood in the light of the development of environmental policy in the Netherlands. Since the late seventies/early eighties, there has been a tendency to replace direct governmental regulation by forms of cooperation with, and self-regulation by industry. It was hoped that in this way, policy goals could be better implemented.

109 According to Winkelaar, the technical secretary of the VVVF, paint recipes are renewed every three to four years. So, paint producers are used to developing and fine-tuning new types of paints. But, as we have seen, the development of paints with fewer VOCs is technically more difficult and will require major changes in recipes or entire new ones. This will require a lot of extra R&D efforts, as is also reflected in the earlier mentioned R&D statistics of the paint industry.

110 *Cf.* Meredith & Wolters, *Op. cit.*.

111 Mol, *Op. cit.*, 158.

112 Van de Peppel, *Op. cit.*, 221-226.

113 *Ibid.* and *Verfkroniek* 61(1988)7/8, 294-295. VOC reduction objectives for a number of branches were formulated. Local authorities were supposed to incorporate the striving for VOC reduction in the licensing of permits. Further it was clear that the government might consider compulsory measures if little success would be achieved and if at the meantime technically and economically feasible alternatives would be available.

114 *Verfkroniek*, 67(1994)2, 8.

115 In 1993, a complete assortment of acrylate paints and high solids for all colors was available in the Netherlands. Recently, also water-based natural paints have been developed. The Ministry of Environment and environmental groups like *Milieudefensie* advise to use water-based acrylate paints, high solids or water-based natural paints.

116 Mol, *Op. cit.*, 147.

117 Estimates on the market share of water-based paints differ from each other, depending on the method of survey and the kinds of paints counted as water-based paints. Nevertheless, the surveys seem to indicate a stagnating market share for water-based paints in the DIY sector (information from the VVVF, July 1996).

118 Only with respect to solvents, acrylate paints scored better. In other respects, they were worse, according to the Bancken Report (Van de Peppel, *Op. cit.*, 253-256).
There has been much discussion about the relative environmental consequences of different paints. Some reports say that acrylate paints are preferable, other reports support natural paints and even traditional alkyd paints are sometimes supported. Typically, the assessment of the environmental effects of paints takes place under much uncertainty. To an important extent, the outcomes of the different studies depend on the presuppositions made in the study and the phases of the life-cycle of paints that are included in the environmental assessment. For the environmental aspects of different paints, see A. Klingenberg, *Alternatieven voor organische-oplosmiddelhoudende verf en houtverduurzamingsmiddelen* (Utrecht: Stichting Natuur en Milieu, 1986); H. Meijer, J. Roorda & W. Verweij, *Verf heeft lak aan het milieu; een verkennend milieukundig onderzoek* (m.m.v. G. IJff en E.P. Smit) (Groningen: Milieukundig Studiecentrum, 1983), Serie studentenverslagen nr. 33; C.H.M.J. Merkx, 'Korte verkenning van de milieu-aspecten van verf' (Wageningen, 1991); Mol, *Op. cit.*, 147 and *NRC Handelsblad*, 18 April 1991.

119 Another reason why acryl paints are environmentally harmful is that they contain biocides to conserve the paint in the can. Moreover, it is sometimes feared that people will wash out the paint brush and the remaining paint under the tap and flush it through the kitchen sink, instead of conserving it as chemical litter.

120 Van de Peppel, *Op. cit.*, 254-255. Another important point of critique was that Bancken uncritically used Akzo-specific data for his calculations. According to an employee of the KWS 200 bureau, acrylate paints of Akzo contained 11% co-solvents, while other producers sold acrylate paints with about 2.5% co-solvents. The fact that the maintenance schemes of Akzo were taken as starting paint would account for about 40% extra use of paints compared with the maintenance schemes of other manufacturers.

121 *Verfkroniek*, 67(1994)2, 12.

122 *Ibid.*

123 A test of the *Consumentenbond* (Consumers' Association) in 1994 showed that water-based paints and high solids equal the quality of conventional solvent-based alkyd paints. They are as easy to apply and give esthetically good results. Nevertheless, water-based paints are still often treated very skeptically (*Consumentengids*, 42(1994)10, 628-633**)**.

124 According to Mol (*Op. cit.*, 189), for some time, a Gentleman's Agreement existed among the VVVF members not to use environmental arguments in advertisements on paints. According to him, this agreement has now eroded and since 1993, advertisements have increasingly appeared stressing environmental advantages of some paints. It seems that such advertisements are especially to be found at the so-called 'environmental page,' an advertisement page that appears in some papers and on railway stations. I have not found other advertisements for paints paying attention to environmental aspects.

125 *Cf.* Mol, *Op. cit.*, 178.

126 *Ibid.*, 165 and telephonic communication Winkelaar, VVVF, July 1996.

127 Mol, *Op. cit.*, 191.

128 Van de Peppel, *Op. cit.*; and N. Nelissen, H. van Boxtel & M. Lemmen, *Beleidsstijlen van managers ten aanzien van het milieu; Een onderzoek naar beleidsstijlen van managers in de verf- en schildersbranche* (Zeist: Kerckebosch, 1991), 165-169; *Verfkroniek* 64(1991)6, 339-242; 65(1992)3, 14-15; 67(1994)5, 8-10 and 69(1996)4, 29-40.

129 *Cf.* Nelissen *et al.*, *Op. cit.*.

130 Van de Peppel, *Op. cit.*, 250-251 and Nelissen *et al.*, *Op. cit.*, 165-169.

131 Nelissen *et al.*, *Op. cit.*, 166.

132 Mol, *Op. cit.*, 147; telephonic communication Winkelaar, VVVF, July 1996.

133 Van de Peppel (*Op. cit.*, 261) did not found a relevant relation between the attitude of the painter with respect to paints with a lower VOC content and the actual use of such paints. This can mean that painters have little influence on the choice of paints or that they have a passive attitude with respect to these paints.

134 Nelissen *et al.*, *Op. cit.*, 175. This finding applies to acrylate paints.

135*Verfkroniek* 67(1994)5, 8-10.

136 Mol, *Op. cit.*, 177

137 Such larger customers can also more easily be reached by government programs like KWS 2000 to reduce the use of VOC-rich paints.

138 *Verfkroniek* 64(1991)6, 339-242; 65(1992)3, 14-15; 67(1994)5, 8-10 and 69(1996)4, 29-40.

139 *Ibid.*

140 Mol, *Op. cit.*, 181.

141 Doorgeest, *Op. cit.*, 59.

142 *Ibid.*.

143 Doorgeest, *Op. cit.*, 60. Description below of needed adaptations is based on *Verfkroniek*, 66(1993), 42-44; 67(1994)10, 29-32 and 67(1994)10, 20-30.

144 The first means that the application apparatus has to be made of stainless steel or synthetic materials; the second often requires improved possibilities for process control, different application techniques and different applicator habits. Against these disadvantages of water-based paints stand advantages like a smaller danger of fire due to flammable VOCs (and hence lower insurance taxes) and health advantages for the personnel.

145 Doorgeest, *Op. cit.*, 59 and 60.

146 Interview Douma, 19-6-1995.

147 According to Doorgeest of TNO Coatings, furniture producers in principle support the objectives of KWS 2000, but recoil from the technical and economic consequences that an actual switch to products with a lower VOC content require (Doorgeest, *Op. cit.*, 60).

148 G. Brenni, 'A Pragmatic Approach for a Drastic Reduction of the VOC Emissions in Industrial Wood Coatings,' in CEPE (ed.), *VOC-Policy of the European Paint Industry* (Presented by CEPE at the first International Congress on Volatile Organic Compounds, March 1991) (Brussel: CEPE, 1991), 40-48.

149 The aesthetic consequences also hold for a possible route to overcome the high investment cost of new application apparatus. For wooden furniture producers it may become cost-effective to contract out the painting of their furniture. In that case, it becomes more difficult to realize particular aesthetic (paint) features that are typical of a furniture producers. (*cf.* interview Douma, 19-6-1995).

150 The reasons why wooden furniture producers have trouble switching to paints with a lower VOC content may differ from company to company. For example, companies that produce cheap furniture may have major problems with investment costs while other companies have more problems with aesthetic differences.

151 Intverview Douma, 19-6-1995.

152 Telephonic communication Winkelaar, VVVF, July 1996.

153 Mol, *Op. cit.*, 196.

154 Interview Winkelaar, 15-8-1995.

155 Mol, *Op. cit.*, 170-171 and 189. 'Responsible care' is an initiative of the chemical industry at large.

156 *Ibid.*, 153-162.

157 *Ibid.*, 186-189.

158 *Ibid.*, 204.

159 *Ibid.*, 175-176.

160 The description of natural paints and their development is based on Mol, *Op. cit.*, 198-204; Nelissen *et al., Op. cit.*, 170-174. Interview Wark, 15-5-1995; information materials from Aquamarijn; *Eisma's Vakpers*, 96(1995)24, 26-28.

161 These principles are:

- intervention in chemical structures is less 'profound' than in the case of 'hard chemistry';
- technology and production processes are adapted to the properties of natural resources instead of standardizing natural resources and adapting to Fordist production processes;
- use is made of the co-productivity of nature instead of seeing nature as mechanical/cybernetic;
- the use of renewable natural resources should not lead industrialized agriculture at a large scale. (Mol, *Op. cit.*, 199).

162 Mol, *Op. cit.*, 200.

163 This is disputed by some adherents of natural paints, but the KWS 2000 program does not treat terpentine different from the VOCs. Also, environmental groups have, for such reasons, taken an ambivalent position toward natural paints. By now, water-based natural paints are on the market.

164 Mol, *Op. cit.*.

165 One reason for branch organization to go against the (short-term) interests of their members is that other members may urge them to do so. In the case of paints, the large paint manufacturers - for example - sometimes opted for measures by the VVVF in order to improve the image of the sector as a whole and, by that, their own image. The policy of a branch organization should, however, not only be understood in relation to its members, but also in relation to the government and to its position and role within the technological regime.

166 Quoted in Mol, *Op. cit.*, 165.

167 For the notion of protected space, see Van Lente (1993), Rip (1992) and Schot (1992) and the discussion in Chapter 8.

168 *Cf.* Van den Belt & Rip (1987) for the notion of exemplar in technological development.

5

Caring for Productive Animals?

Chicken Husbandry Systems and Sewage Treatment Plants

Users usually play an important role in the acceptance of innovations. In some technological regimes, they also play an important role in the development of such innovations. Either because they themselves are directly involved in design and innovative activities or because most design and R&D activities in the regime are primarily guided by functional requirements of users. If users play such a role in a technological regime, we can say that the technological regime has a user-driven innovation pattern. A user-driven innovation pattern is characteristic for both technological regimes that I will discuss in this chapter, that of chicken husbandry systems and that of sewage treatment plants.

In this chapter, processes of transformation with respect to the technological regimes of chicken husbandry systems and sewage treatment plants are studied. In the case of chicken husbandry systems, the studied process of transformation was initiated in reaction to the aggression of the existing technological regime. According to animal welfare groups, the introduction of the battery cage worsened the living conditions of laying hens. In several ways, they tried to replace the principle that had guided battery cage design, research and use until then, 'efficiency', by the new guiding principle 'animal welfare.' They did so via the routes of regulation, user pressure and delegitimation. The first two routes were already discussed in the preceding chapter. The third route implied an attempt to delegitimize the existing regime, in the hope that this would lead to a change in the behavior of the actors involved and in the principles that guided their behavior.

The process of transformation in the regime of sewage treatment plants that I will discuss started as a demand upon microbiologists and later biotechnological researchers. These people had to offer, so they could argue, particular knowledge and capabilities with which better treatment plants could be designed. With some success, they tried to get a larger role in the technological regime of sewage treatment plants, first via the formulation of design parameters and later via the effectuation of a new biotechnological design approach.

Transformations in technological regimes with a user-driven innovation pattern can be achieved by changing functional requirements of users. This is both an opportunity and a constraint for outsiders who want to transform a technological regime.

With respect to the feedback of secondary effects in reaction to aggression, it is an opportunity because different routes stand open for outsiders to change functional requirements of users (delegitimation, regulation, user pressure). With respect to the involvement of new professional experts via a demand, changing functional requirements are also an opportunity because then new knowledge or design tools may be required to operationalize and meet the new requirements. Outsider professionals may possess such knowledge and so become involved via a demand. The fact that innovations in a user-driven innovation pattern usually derive from the functional requirements of users constrains the development of particular technical alternatives and so the unfolding of processes of transformation via other routes than changing functional requirements. In the chicken husbandry story, the existing technological regimes constrained the development of alternative welfare-augmenting housing systems for hens because poultry farmers opposed the development of such systems. Therefore, governments had to stand in to initiate the development of alternative systems. In the case of sewage treatment systems, innovations proposed by biotechnological researchers were only accepted as far as it could be proved that they assisted in meeting more stringent effluent standards. Typically, these innovations were first developed in the related technological regime for industrial waste water treatment plants that functioned as a kind of protected space for these innovations.

5.1 Efficiency Versus Animal Welfare[1]

> *The Netherlands has managed to secure a place among the world's largest egg exporters thanks to its efficiently managed poultry farms. The revolution in egg production started in the early 1960's, with the introduction of slatted floors and mechanization of feeding, manure removal and egg collection. A few years later the cage system was introduced and it gained ground rapidly. Pullet rearing units were established simultaneously. At present 90% of the layers and 80% of the pullets are reared in battery cages ...*[2]

> *The use of battery cages, in which 95% of the laying hens in the Netherlands are kept, radically changed the living conditions of the animals. The laying battery is practically the opposite of the farmyard. A laying battery consists of a number of small mesh cages, each with a floor area of 40 by 50 centimeters. In each cage there are four to five hens, placed there when they are seventeen to eighteen weeks old. During the laying period more than 10% simply die. After fourteen months the survivors are pulled out of the cages and put into crates. With broken legs and wings they go into the chicken soup.*[3]

Both these quotations refer to the introduction of the battery cage in Dutch poultry farming. Whereas in the first quotation, the battery cage is presented as an efficient system for the production of eggs, in the second it is condemned as cruelty against animals. The second interpretation has been put forward by animal welfare groups since the sixties and seventies and has gained ground rapidly. This initiated a process of transformation that eventually resulted in the development of a number of alternative animal welfare-augmenting chicken husbandry systems.
This story begins with a brief description of the guiding principle 'efficiency' in chicken husbandry design. In Section 5.1.2, the actual process of transformation is described in detail and in Section 5.1.3, the dynamics of the process of transformation and the resulting transformations in the regime of chicken husbandry systems are recapitulated.

5.1.1 The Drive for Efficiency in Battery Cage Design

In the late sixties and early seventies, the battery cage rapidly replaced the existing slatted floor system for keeping laying poultry.[4] Due to developments in the market for eggs, described in more detail in Appendix 3, efficiency in this period began to function as a guiding principle in battery cage design, research and use. The term 'efficiency' became a common denominator for the actors involved to legitimize their activities.

The different actors developed somewhat different interpretations of what it meant to strive for efficiency. For the users of battery cages, *i.e.* the poultry farmers, efficiency meant in the first place minimal costs per egg produced, that is, a *pro rata* portion of the housing and investment costs, the cost of feeding the chicken, labor costs, etc. With respect to the design of battery cages, the guiding principle 'efficiency' was translated into more specific heuristics and generally accepted layouts for laying batteries. Also, other relevant groups, such as agricultural suppliers and researchers developed specific interpretations of 'efficiency,' which guide their day-to-day practice.

Within the technological regime of chicken husbandry systems, the guiding principle 'efficiency' was translated into more specific functional requirements that began to guide design and research with respect to battery cages. These functional requirements relate to three areas: housing, food and labor. Efficient housing means as many chickens per square meter as possible. However, there is a limit to the number of chickens that can 'efficiently' be held per square meter, because a hen's productivity is dependent on the number of chickens held in a battery cage and the size of the battery cage. Efficiency with respect to food means that 'food conversion' should be as low as possible. Food conversion is one of the parameters used to evaluate the results of tests with housing systems. Efficiency with respect to labor is generally achieved by different forms of mechanization, for example with respect to feeding, egg removal and manure removal. As a rule, these forms of mechanization are easier to implement in battery cages than in traditional housing systems.

At present, after several decades of development, the search for more efficient systems has become a matter of detail design. Smaller design adaptations and innovations are usually accomplished at research institutes and at the firms producing battery cages. With respect to research an important role is since the 1920's played by what is nowadays called the 'Spelderholt Center for Poultry Research and Extension.'[5] At the *Spelderholt*, research is done on poultry housing, egg-quality and feeding.[6] Research at the *Spelderholt* is paid by the government and the poultry farmers. Usually it is practice-oriented and guided by the guiding principle of efficiency and functional requirements of poultry farmers.

5.1.2 Attacks on the Hegemony of the Battery Cage

In the sixties, when the changeover to the battery cage was still under way, the first criticisms of the effects of the battery cage on animal welfare began to be heard. In 1964, Ruth Harrison published the book *Animal Machines*. Nowadays, this book is widely regarded as the first resistance to intensive livestock farming in general, and particular animal husbandry systems, like the battery cage, in particular. In her book Harrison argued that:

> *Most people, especially in towns, tend to be ignorant of the processes by which food reaches their table, or if not ignorant they find it more comfortable to forget. Farm produce is still associated with mental pictures of animals browsing in fields and hedgerows, ... , of hens having a last forage before going to roost, ... , and all the family atmosphere embracing the traditional farmyard. This association of ideas is cleverly kept alive by the giants of the advertising world who realise that the public still associates quality with healthy surroundings. A picture of ... the battery hen cramped in its cage ... would not, they rightly surmise, help to sell their products.*[7]

In the remainder of the book, Harrison attacked the drive for efficiency in animal husbandry on the modern farm. She suggested that developments in factory farming had alienated the farmer from his or her animals:

> *The factory farmer cannot rely, as did his forebearers, on generations of experience gained from animals themselves and handed down from father to son; he relies on a vast array of backroom boys with computing machines working to discover the breeds, feeds and environment most suited to convert food into flesh [or eggs, IvdP] at the greatest possible speed ...*[8]

As a result, animals such as laying hens were reduced to production machines according to Harrison:

> *[T]he chief aim of intensive egg producers is to make chicken into a super-efficient machine for laying more and more eggs in a given time, and if, after all, she bears little relation to the chicken as we knew it, who cares?*[9]

In her book, Harrison tried to create a negative public image for the battery cage and other intensive livestock systems by connecting effects of this system with the neglect of 'animal welfare.' Harrison was rather successful in doing so. Her book was also widely read outside England.

In the Netherlands, two new animal rights groups were established in the early seventies: *Lekker Dier* (Nice Animal) and *Rechten voor al wat leeft* (Rights for all that lives). These promptly attacked the battery cage. Later, they were joined by the *Dierenbescherming* (Dutch Society for the Protection of Animals), which had already been established in the 19th century. These groups succeeded in capturing the attention of the media and several politicians.[10] In their campaigns, the animal rights groups adroitly exploited the fact that people do not like to see animals suffer. In this way, they dramatized the tension between the drive for efficiency in the design of battery cages and more generally accepted humane values.

While Dutch animal rights groups soon succeeded in capturing the attention of the media and several politicians, they had little direct impact on the design and use of battery cages. It was especially the group *Rechten voor al wat leeft* that therefore tried to mobilize economic leverage against the battery cage. Starting in 1972, it tried to introduce an alternatively produced egg onto the Dutch egg-market, *i.e.* one not produced in battery cages.[11] This so-called *scharrelei* (scratching egg)[12] was produced in chicken sheds with slatted floors, in which at least a third of the ground area was not covered with slats, to give the chickens the possibility to 'scratch.'[13] Such sheds with slatted floors were still in use on some farms in the early seventies; however, the eggs produced at these farms could not be distinguished as scratching eggs by the consumer. This spurred animal rights groups to develop a 'label' that could be given to eggs produced in systems more benign to animals than battery cages. Farmers did not like the idea of selling discernibly different eggs, probably because it would imply recognition of the fact that battery chickens lived in worse circumstances.

In 1974, the first scratching eggs were put onto the market at a somewhat higher price than 'normal' eggs. Thenceforth, it became possible for consumers to choose between 'benign' and 'cheap' eggs. However, authenticating the origins of the scratching eggs - which initially was done by the group *Rechten voor al wat leeft* - was problematic, partly because no legal procedures for certification existed. Incidental fraud was reported. In an attempt to save the situation, the Dutch government issued a *Landbouwbesluit Scharreleieren* (Agricultural Decree on Scratching Eggs) in 1978, enforceable as of January 1979. This decree created a new certifying authority: the *Stichting Scharreleieren Controle* (Foundation for the Certification of Scratching Eggs), later followed by the *Stichting Nederlands Eiercontrole Bureau* (Foundation Netherlands Egg Certification Office). This authority, in which farmers, egg distributors, and animal rights groups participated, became responsible for authenticating the origins of scratching eggs. To make scratching eggs easily recognizable for the consumer, a special stamp (a little lion) was designed. The stamp, as well as the word *scharrelei* (scratching egg), became legally protected.

The institutionalization of a new market for more benign eggs not only required legal procedures, but also the cooperation of the egg distributors and supermarkets. In 1976, Albert Heijn, a large Dutch supermarket chain, undertook a trial with scratching eggs in ten of its stores. The trial was successful and an important channel for distribution was created. The sale of scratching eggs increased until 1982, but then stagnated. The main reason was held to be the limited availability of scratching eggs. Therefore, in 1984 the *Dierenbescherming* started a national campaign to promote the sale of scratching eggs. Supermarket chains, the hotel & catering industry and the bakery sector were approached. The *Dierenbescherming* not only tried to create new distribution channels, but also developed special stickers to make the use of scratching eggs in bakery and restaurant products more visible. As a result of this campaign, the consumption of scratching eggs started rising again. The number of scratching eggs delivered to packing stations rose from 218 million in 1984 to 632 million in 1990. In 1991, approximately 10% of the laying hens in the Netherlands were kept as scratching hens.[14] In fifteen years, the scratching egg has captured 20% of the domestic egg market. However, as things now stand this may remain only a limited success.[15] A large part - about three quarters - of the eggs produced in the Netherlands is exported and scratching egg plays only a limited role in this export. Moreover, most eggs used in the egg-based foods industry are not discernable as either battery cage or scratching eggs for the end consumer.[16]

A Demand Upon Ethologists

Criticizing the battery cage or promoting alternative eggs required explaining why chickens suffered in battery cages and were better off in alternative systems. For animal welfare groups, it was quite clear that the battery cage was an inhumane system. For others, no clear proof existed that hens in battery cages suffered. Take, for example, the following commentary by a farmer on the purported humaneness of an alternative system (the aviary: a system with somewhat lower productivity): 'If chickens felt better in an aviary, they would also produce better. But they don't.'[17]
As in many societal controversies, scientists were called in by the contestants to buttress their respective positions. Science in this case, at least for the critics of the battery cage, meant ethology. Ethology is a branch of biology that studies animal behavior. Ethology had already played a role, albeit a marginal one, in the design of battery cages. In the fifties, for example, important ethological research had been done on the social behavior and status hierarchy of chickens in relation to their egg production. This research no doubt had an impact on the development of the battery cage.[18]
Although ethological welfare research on chickens was not widely carried out until the sixties, ethologists were among the first to criticize the battery cage in countries like England, the Netherlands and Germany.[19] This is not quite surprising. The disciplinary basis of ethology is the study of the behavior of animals in their natural environment. This 'natural' behavior gives ethologists a kind of reference point with respect to which they can claim to discern 'abnormality' in the behavior of, for example, chickens in battery cages. Deviant or absent behavior can then be interpreted as possible failure of the animal to adapt itself to the new environment.

Box 5.1 *Ethology and Animal Welfare*

The opinions of ethologists on animal welfare are not unanimous. For some, there is no unequivocal scientific evidence for the suffering of animals in, for example, battery cages. Others have not only criticized intensive housing systems but also blamed (classical) ethology for objectifying animal behavior and ignoring the subjective feelings of animals.
Some ethologists have now developed definitions of animal welfare that are based on a notion of animal consciousness or animal emotions. One way to argue for the existence of subjective feelings in animals is by the analogy postulate. This postulate states that as far as the behavior and physiology of humans and animals are analogous in significant respects, there are grounds for assuming that animals have feelings and can suffer. Another way to argue for the existence of animal consciousness or animal emotions is to see such consciousness or emotions as one of the factors shaping behavior. According to this argument, consciousness can be empirically observed - at least indirectly - by studying animal behavior.
Both arguments for animal consciousness may imply a break with the existing paradigm in animal research and are unacceptable to some other ethologists. Clearly, the issue of animal welfare has fired fundamental discussions within ethology. Typically, the classical ethological model of Lorentz has been used both to prove and to refute the assertion that chickens suffer in battery cages. Moreover, ethologists have also been confronted with conflicting views from other disciplines, like veterinary science.

So, ethology as a science has a normative standard by which to judge the suffering of animals. Moreover, as part of their professional life, most ethologists studied animals intensively and over long periods. According to some observers this made them more sensitive to animal welfare than, for example, veterinary scientists.[20] Of course, this did not mean that all ethologists agreed on the level of animal welfare in battery cages or on possible measures that might be taken (see Box 5.1).[21] However, ethology at least offered some instruments and concepts with which to say something about animal welfare.

Governments also called in ethologists. In the sixties and seventies, governments were under public pressure to take measures to encourage animal welfare in intensive livestock farming. The British government, for example, installed a committee on animal welfare six weeks after the appearance of Harrison's book *Animal Machines*. This committee, named after its chairman Roger Brambell, a well-known professor of zoology, also included the ethologist William Thorpe. The report of the Brambell Committee appeared at the end of 1965. It defined animal welfare as

> *[A] wide term that embraces both the physical and mental well-being of the animal. Any attempt to evaluate welfare must take into account the scientific evidence available concerning the feeling of animals that can be derived from their structure and functions and also from their behaviour.*[22]

According to the *Brambell Report*, animals' feelings can be evaluated by analogy with human feelings and can be derived from observation of the animals' behavior, cries, expressions, reactions, health and productivity. According to the *Brambell Report*, a (farm) animal should not be frustrated in 'the major activities which make up its natural behavior.'[23] More concretely, the committee recommended that 'An animal should at least have sufficient freedom of movement to be able, without difficulty, to turn around, groom itself, get up, lie down and stretch its limbs.'[24] This recommendation has become known as the Brambell five freedoms.
On the basis of these and comparable criteria and insights, ethologists have developed more detailed requirements for welfare-augmenting housing systems. With respect to housing systems for chickens the following kinds of requirements are often named: the number of hens per square meter, the possibility for chickens to 'scratch' and take 'dustbaths' (presence of 'litter'), the presence of laying nests (to lay eggs in) and the presence of perches.[25] These requirements also came to function as heuristics for the development of alternative systems.

The Development of Governments Regulations

Most West European countries have adopted, in the course of time, generic laws to protect animals. Many of these laws have a formulation referring to the 'ethological needs' of animals. Animal rights groups have tried to use such laws to sue farmers that kept chickens in cages. However, in most cases they have not been very successful in their litigations.[26] One of the few exceptions is Germany. In 1979, several German courts declared that hen batteries violated provisions of the German animal protection law of 1972. However, the defendants were not prosecuted because it was judged that they could not have known that this *common practice* was illegal.[27] As a result the German government changed the law, and meanwhile started pressing the EEC for issuing legislation with respect to animal welfare in battery cages.

As a result of German pressure, the EEC started a number of consultations to evaluate the feasibility of a ban on the battery cage in the eighties. Eventually, a ban was not concerned feasible. Nevertheless, in 1986 EEC rules with respect to laying batteries were laid down in Directive 86/113/EEC.[28] This directive stipulated the minimum requirements for laying batteries coming into use after 1 January, 1988. These requirements were also to be applied to *existing* battery cages as of January 1995.[29] The requirements were at least 450 cm^2 floor area per hen, 10 cm feeding trough per bird, 40 cm height over at least 65% of the area and a floor-slope of maximally 14%.[30] In most West European countries, these requirements are now mandatory. In some countries, requirements for the floor area are more stringent. In Denmark, for example, the minimum requirement is 600 cm^2 per hen; in Germany and England the requirements are more stringent for heavier chickens or for fewer than four hens per battery cage.[31] Clearly, however, such national and international requirements did not compromise the legality of the battery cage.

One country that, at the moment, has such stringent legal requirements for chicken husbandry systems that they amount to a ban on the battery cage is Switzerland. In this country the animal rights group *Schweitzer Tierschutz* succeeded in achieving a referendum on the issue. In this referendum, it was decided to phase-out the conventional battery cage in ten years, starting in 1981. In 1989, Sweden also started with a ten-year phase-out.

The Development of Alternative Systems

Ethological research had pointed to some basic requirements and heuristics for welfare-augmenting poultry husbandry systems. By the seventies, these insights began to encourage the development of alternative systems in the Netherlands and other West European countries. In the Netherlands, important research was carried out at the *Spelderholt*.

Bareham's development of the so-called 'get-away cage' in 1976 is generally cited as the international point of departure for applied research on alternative systems.[32] The get-away cage is a battery cage with special areas for perches, laying nests and litter. These special areas increase the quality of the system from the point of view of animal welfare. Initially, most of the research concentrated on modified battery cages, because the scratching system has two major disadvantages: an increased risk of poultry diseases due to the wet litter and an increased risk of cannibalism (chickens killing each other under stress), which is more serious in a scratching system because more animals share the same space.[33]

In time, modified hen batteries apparently had their own disadvantages. The litter in these systems caused problems with respect to eggs laid outside nests and the chickens were more difficult to access and inspect. Moreover, modified hen batteries turned out to be labor-intensive.[34] Therefore, other types of alternative systems were developed. One of them is the aviary or, as it is called in the Netherlands, the ‘volière.’ This system is characterized by the presence of several levels on which the chickens can drink, eat and rest. Because of the different levels, a large number of chickens can be held per square meter of floor area. On the other hand, the aviary allows chickens to scratch, take dustbaths, rest and lay eggs in laying nests.

Alternative systems would probably never have been developed without some form of active interference by governmental bodies. In most countries, research on alternative systems got off the ground only in response to a possible governmental ban on laying batteries or when government subsidies became available. Research institutes did not develop alternative systems earlier because most farmers - *i.e.* the users of the systems and the main clients of most research institutes - were not very interested in alternative systems. Farmers in the Netherlands specifically refused to pay for research on alternative systems that were not based on the battery cage.[35] So, only the government remained as a source of funding for research on alternative systems.

Since governments were interested in a system that would compromise neither animal welfare nor economic considerations, governmentally funded research aimed at a technical compromise between animal welfare and efficiency. The government probably hoped that such a technical compromise would be acceptable to both the critics of the battery cage and its main defendants, the poultry farmers.

In 1984, Dutch parliament passed a so-called initiative law proposed by parliamentarians Tazelaar and Van Noord.[36] Besides specifying minimum requirements for the laying battery, the law charged the Minister of Agriculture with formulating tighter requirements before 1 January, 1990, to become effective as of 1 July, 1994. The law aimed at a ban on the battery cage. As a prerequisite, it stipulated that an economically and technically feasible alternative should first be available. The *Spelderholt* was seen as the legitimate authority to develop and demonstrate such an alternative.[a]

In the same year that the Tazelaar/Van Noord bill was passed, the *Spelderholt* abandoned efforts to modify the battery cage and concentrated its research on aviary systems. The development of the *Spelderholt* aviary was completed in 1986. In 1988, a series of comparative tests with the battery cage was started.[37] The first round of these comparisons was favorable for the aviary.[38] Based on this success, the Minister of Agriculture expressed his intent to forbid the battery cage as of July 1994. Director De Wit of the *Spelderholt* appeared to support this decision:

> *The battle of the battery is lost. We need entertain illusions no longer; there will be a ban on the battery. The challenge now is to manage the*

a In 1984 an alternative system was in principle already available for the Dutch market because in 1981 LACO BV, a Dutch producer of laying batteries, had started producing aviary systems for the Swiss market. LACO also sold these aviaries in Belgium, Great Britain and the Netherlands. Obviously, the politicians did not see the existence of this system as proof that a feasible alternative was available. And apparently the politicians looked to the *Spelderholt* for the answer to the question: ‘Can a feasible alternative be developed?’

transformation in such a way that the Dutch poultry industry comes out unscathed.[39]

At the same time, De Wit defined the *Spelderholt* system as fully developed:

> *Research has done what it can do. Politics and economics must now speak. We think that the price difference of 0.8 cents [per egg, IvdP] cannot be reduced by further modifications to the floor system [aviary, IvdP]. All cost increases are now due to welfare augmenting measures. Less is impossible.*[40]

The farmers firmly rejected the impending ban on the battery cage. Vigorous discussions between proponents and opponents of the battery cage followed. These discussions, fired by the success of the first round of the comparative tests at the *Spelderholt*, encouraged further comparisons between the battery cage and the aviary.
The subsequent second round of tests had to be terminated because of a defect in the feeding system.[41] In an article in the magazine *Pluimveehouderij* (*Poultry Husbandry*) staff members of the *Spelderholt* speculated on why the second test with the aviary system failed. In so doing, they seemed to hedge on the more politically loaded statements of director De Wit:

> *In the first place: staff members of 'The Spelderholt' and the IMAG have designed and tested the aviary system and have interpreted and published the results to the best of their ability. All along, we have stated that more research is needed before definitive conclusions can be drawn.*
> *Secondly: the research in question has no bearing on possible policy decisions with respect to the use of this and/or other housing systems in practice.*[42]

These efforts to keep the political and technical dimensions separate were not very successful. In the press, at least, the technical and political issues were indiscriminately discussed. For example, in the *Agrarisch Dagblad* (*Agricultural Daily*) of 8 November 1990, it was reported that De Wit rejected speculations that the third round of comparative tests was going to be a failure. The same article also reported that Tazelaar - former member of parliament, coauthor of the 1984 law and now, ironically, chairman of the *Produktschap voor Pluimvee en Eieren* (Product Board for Poultry and Eggs) - considered a ban on the battery cage unacceptable:

> *An acceptable alternative system is presently not available. If the laying battery were to be abolished in our country at this time, laying poultry farming will also be abolished. Enforcement has to take place in Europe as a whole. I do not think that likely by 1994.*[43]

Van Noord, the other former proponent of the Tazelaar/Van Noord bill, had already said something similar in 1989.[44] Indeed, parliament ultimately decided to delay the enforcement of the law for an indefinite period, the main reason being potential economic damage to the farmers. It was therefore decided to keep pace with the EEC, now the EU (European Union).

The Acceptance and Spread of Alternative Systems

A number of alternative systems are now on the market. The Dutch firm LACO BV has been producing aviaries since 1981, initially for the Swiss market, where the battery cage is legally banned. At the moment, LACO BV also sells these aviaries in Great Britain, Belgium and the Netherlands. Since 1990 the aviary designed by the Spelderholt has been produced by the Dutch firm Rijvers BV. A number of foreign firms also produce aviaries.

Most farmers do not want to buy and use these aviary systems because they imply higher production costs per egg. According to the poultry farmers, the system has other disadvantages as well: aviaries are more labor-intensive, they produce more dust that further aggravates labor conditions and entail a greater risk of poultry diseases due to the litter.[45] Moreover, aviary systems have a higher ammonia emission. As environmental pollution standards become more stringent in the Netherlands, this is becoming an important disadvantage for the aviary. Currently, the Spelderholt is investigating how to reduce the aviary's ammonia emissions.[46] Since the aviary's higher ammonia emissions are mainly due to the presence of litter, which is seen as a prerequisite for animal welfare, animal welfare requirements seem to conflict with required lower levels of ammonia emissions.

5.1.3 Transformation of the Technological Regime of Chicken Husbandry Systems

The process of transformation toward welfare-augmenting chicken husbandry systems started when animal right groups protested against the neglect of animal welfare in (the design of) battery cages. This neglect of animal welfare was an unintended effect of the battery cage, but it was not unforeseen.[47] One reason why Dutch farmers in the thirties were hesitating to adopt the battery cage was that they disliked the factory-like way of keeping chickens.[48] Animal welfare was simply initially not taken into account in the design of battery cages. It was treated as a secondary effect.

In response to this secondary effect, animal welfare groups tried to delegitimize the battery cage by connecting its secondary effects with the neglect of particular humane values. For two reasons, the attack on the laying battery started with criticizing its legitimacy. The first reason is the protesters' heartfelt rejection of the simple fact that efficiency instead of considerations of animal welfare guided the design and use of battery cages. The other, related, reason is that mobilizing the public on an issue like animal welfare is relatively easy. Humane values, at least as values, are deeply rooted in Western civilization. Few would contest that it is inhumane to let animals suffer unnecessarily. (The question, of course, then becomes: 'What is unnecessary?').

Animal rights groups adroitly exploited the fact that people do not like to see animals suffer. In this way, they dramatized the tension between the guiding principle of 'efficiency' and generally accepted humane values. The technical language used by the designers of battery cages tended to veil this tension. 'Dropout rate' sounds better than 'percentage of chickens killed' or even 'mortality rate.' A term like 'food conversion' sounds more neutral than giving chickens just enough food to lay good eggs and to survive. In most advertising brochures, the battery cage looks not only like an efficient system, but also like a very clean one. Some battery cage producers have even presented 'traditional' battery cages with a slightly larger floor area per hen as 'welfare-augmenting.' The parties involved are quite aware of the ideological bearings of their words and pictures. For example, farmers and their organizations like to talk about 'intensive livestock farming,' whereas opponents prefer the word 'bio-industry.'

Although poultry farmers and battery cage producers were sensitive to the 'ideological' critique on the battery cage, the protests of animal welfare groups had little direct bearing on the design of battery cages. Especially, poultry farmers have resisted animal welfare as important design criterion or guiding principle. One reason why poultry farmers were not so easily persuaded is, no doubt, their unreflective commitment to the 'normal' way of doing things. This is probably why poultry farmers claimed to be misunderstood and reacted angrily when the outside world started criticizing their methods. The specific resistance of this group, however, must also be understood as an effect of encapsulation in the existing guiding principle of 'efficiency.' Interactions between them and other actors were organized around this guiding principle. For example, farmers are dependent for credit on good relations with financiers, who expect them to produce efficiently. It is therefore far too easy to accuse chicken farmers of simply being traditionalists or conservatives with an aversion to new technology. Nor are they necessarily unreflective adherents of efficiency. It may even be the case that their personal attitudes conflict with the guiding principle, but that they nevertheless act according to this principle because it organizes their relations with relevant actors. This does not, however, explain why poultry farmers objected so much more to aviaries and other alternative systems than the other actors involved like the *Spelderholt*. To understand this, we have to take into account the economic competition among the farmers and the mechanism of market selection. (Like guiding principles, this mechanism was discussed in Chapter 2).

Poultry farmers have to sell their eggs at a price that at least compensates the costs of production. Of course, this can be done by trying to create a new market for 'benign' eggs, but this entails an economic risk for the farmer, unless the feasibility of such a market can first be proven. The existing market brings about an investment structure, in which departure from the efficient production of eggs implies serious risks. Clearly, this is an incentive for farmers to stick to the existing guiding principle. Moreover, the selection of farmers and technical systems takes place partly behind the backs of these actors. For example, in the fifties, the economic restructuring of the Dutch laying poultry sector selected for those farmers who were more successful in striving for efficiency. As a result of this selection, the remaining farmers were also encouraged to develop a disposition to efficiency. Of course, at the *individual* level, market structures do not automatically produce a bias toward efficiency. Actors react to their perceptions of the market, not to some 'real' market situation.[49] However, market selection can lead to a bias for efficiency on a *collective* level, because farmers not producing efficiently enough have a greater chance of going bankrupt. Moreover, bankrupt farmers provide a frightening example for the survivors. This will reinforce the conviction that it is very risky to switch to husbandry systems that may be not as efficient as the laying battery. This conviction may cause (some) farmers to start producing more efficiently or encourage the development of more efficient laying batteries. Subsequently, additional businesses may go bankrupt, providing new evidence for the conviction that only those producing efficiently, *i.e.* using laying batteries, have a chance to survive, et cetera.

Because poultry farmers resisted alternative systems, designer/producers of battery cages did not immediately develop alternative systems when the battery cage came publicly under fire. As might be expected in a regime with a user-driven innovation pattern, designer/producers followed the functional requirements of users in developing (alternative) systems. They developed welfare-augmenting systems when they expected market demand for such systems, for example when some governments banned the battery cage. However, the delegitimation of the battery cage was in itself not enough to initiate the development and production of alternative systems.

Since the critique on the existing guiding principle of 'efficiency' and attempts to introduce 'animal welfare' as new guiding principle did not affect the design of chicken husbandry systems directly, two other routes stood open for animal welfare groups to create leverage against the existing regime. These are the two routes I already discussed in Chapter 4: regulation and user pressure.[a] These routes could not be effectuated by animal rights groups themselves. They needed to win allies against the battery cage. Partly, they did so via what can be called a *delegitimation detour*. By connecting the negative (secondary) effects of the battery cage to the neglect of generally held values, they tried to persuade governments and users to undertake actions against the battery cage, which animal welfare groups themselves were not able to undertake. This delegitimation detour was a relatively cheap and effective strategy to win allies against the battery cage. In the event, it paved the way for the routes of regulation and user pressure.

Regulation

Governments quickly accepted a general responsibility for the protection of animal welfare. This also led to more stringent requirements for battery cage design.

a Here, user pressure does not refer to the mobilization of the direct users of the systems, the poultry farmers, but to the users of the users, the egg consumers. The route is, however, comparable to the one discussed in Chapter 4 because it is essentially an economic one and takes place via what Schwartz Cowan has called the 'consumption-junctions' of a technology (Schwartz Cowan, 1987).

The requirements formulated by the EU have now become more or less the standard for cage design in the EU countries.
When it came to a ban on the battery cage, most (EU) governments were more hesitating. For most governments, the protection of the economic interests of their farmers was at least as important as augmenting to the welfare of laying hens. In Switzerland, where the battery cage was banned, the interests of poultry farmers were little harmed. This is due to circumstances that are somewhat unique to Switzerland. The country exports no eggs and the internal market is protected by protectionist measures, which Switzerland can take because it is not a member of the EU.[a]

Banning the battery cage, in the eyes of the government, required the availability of technical alternatives. Alternative systems were mainly developed by research institutes like the *Spelderholt*. This research was financed by governments. It led to an articulation of design requirements for welfare-augmenting systems by ethologists and to the development of several alternative systems.
Poultry farmers, who usually initiate innovations in the regime of chicken husbandry systems by posing new functional requirements and financing research, undertook no proactive activities with an eye on a possible ban on the battery cage. For a long time, they refused to pay for research on welfare-augmenting systems.[50] So, unlike the supplier-dependent innovation pattern discussed in the preceding chapter, regulation was not enabled by proactive activities of the industrial actors themselves. This did not mean that no alternatives could be developed. It meant that the government had to take the responsibility for the development of such alternatives. This had consequences for the acceptance of such systems by farmers.
When the Dutch government considered a ban on the battery cage, it asked the *Spelderholt* to develop alternatives and to assess their (economic) feasibility. One reason why the government turned to the *Spelderholt* was probably that it thought that this institute would also be accepted by the farmers as an important authority with respect to the feasibility of alternative systems.[b] The *Spelderholt* is the main research institute in the poultry sector. Apart from the government, poultry farmers are the main clients and financiers of the *Spelderholt*.

a In Switzerland, there are a large number of small poultry farms. The internal price of eggs is relatively high. Swiss egg importers are legally required to spend a particular percentage of every Franc they spend on imported eggs, on eggs produced in Switzerland by small farms. Moreover, imported eggs intended for direct consumption have to be recognizably stamped. Despite this measure, more than 50% of the eggs consumed in Switzerland - those for direct consumption as well as those destined for egg-products - is imported. Nonetheless, the ‘percentage rule’ protects existing Swiss farms from a further decline in their market-share. This rule combined with the relatively high internal price level for eggs, explains how the Swiss government could relatively easily ban the battery cage without fear of major adverse effects on Swiss poultry firms. (Information from the Dutch Product Board for Livestock, Meat and Eggs; D. Meierhans, ‘Legehenenhaltung; Alternativen in der Schweiz (I),’ *DGS*, 43/1992 (1992), 1251-1257).

b Typically an alternative was already available, but the Dutch politicians probably thought that they had better chances to convince the farmers of the feasibility of alternatives, if these alternatives had been developed and tested by the *Spelderholt*. See also footnote on page 127.

The government also tried to make technical alternatives more acceptable to the poultry farmers by asking the *Spelderholt* to develop an alternative that would meet requirements of efficiency and requirements of animal welfare. The eventual tradeoffs between efficiency and animal welfare of the resulting aviary system were, however, considered unacceptable by the farmers. They thought that the substitution of the battery cage by the aviary would introduce too large economic risks.

The resistance of poultry farmers against the aviary was also due to the fact that the government interpreted the research at the *Spelderholt* in terms of the (political) question: 'Should the battery cage be banned?' This gave poultry farmers, and their organizations, an additional strategic motive to resist the aviary. In other words, poultry farmers judged the aviary not only in terms of its 'technical' performance but also in terms of its possible political consequences like a ban of the battery cage.[51] The coupling of the development of alternative systems with a possible ban on the battery cage then did not encourage the acceptance of such alternative systems by farmers.

User Pressure

Animal welfare groups also tried to create leverage against the battery cage by the mobilization of eggs consumers. The fact that some chickens were still kept in sheds with slatted floors, later renamed as scratching systems, enabled this attempt. It meant that alternative, somewhat more humane eggs were in principle available.

The introduction of alternative eggs further required three things. In the first place eggs had to become distinguishable as either battery cage or alternative eggs. In other words, the 'contribution' of particular eggs to the neglect of animal welfare had to be unblackboxed. This was done by the introduction of a special label. This process of unblackboxing is comparable to what we saw in the refrigerator case in the preceding chapter. Second, the introduction of alternative eggs required institutions and legal procedures to monitor the origins of eggs distinguished as 'alternative.' Third, arrangements had to be made to sell scratching eggs through existing distribution channels.

The introduction of the 'scratching egg' was rather successful in the Netherlands. Despite the somewhat higher price of alternative eggs, some ten per cents of the domestic sales of eggs consist of scratching eggs and other alternative eggs. Overall, the success of alternative eggs is limited. An important reason is the layered structure of the egg market. Eggs produced by poultry farmers are not only bought by end consumers but also by the egg-based food industry. The latter is far more sensitive to the price per egg than the direct consumers of eggs and, as a rule, not willing to pay more for 'benign' eggs. Some attempts have been undertaken to make visible the use of alternative eggs in the end products of the egg-based food industry, but until now the success of such attempts have been limited.

More important than the actual market demand for scratching eggs, is perhaps the creation of an infrastructure around the production and sale of these eggs. This infrastructure can also be used for the certification and sale of other alternative eggs. At the moment, various kinds of alternative eggs are specially stamped and sold. These include aviary eggs and eggs from systems that are more radically different from the battery cage than the scratching system and the aviary and augment more to animal welfare. As far as such alternative eggs are sold, the creation of an infrastructure around the sale of alternatives eggs has created the opportunity to use alternative systems in an economically viable way. This has important consequences for the further technological development of alternative systems. As the Dutch *Dierenbescherming* has recognized:

> *The development of alternative 'scratching' products has very far reaching consequences for animal livestock farming. In fact, it creates separate fields with their own technologies and interests, which, in part, differ significantly from those of the bio-industry. The rise of these fields has, on the one hand, led to an increase in practical knowledge of these alternative forms of housing; on the other hand, it has spurred scientific investigations into optimization of these alternatives. Psychologically and politically it is very important that alternative housing systems show that it is now possible to keep animals in more humane ways than in the bio-industry and that this can be done in an economically viable way.*[52]

As this quotation suggests, the existing market niches for alternative eggs constitute protected spaces for the further development and optimization of alternative systems.[53]

The creation of an infrastructure for alternative eggs then implies an enduring transformation of the regime of chicken husbandry systems. It has created new possibilities not only for the sale of eggs, but also for the development and optimization of alternative systems. This does not necessarily imply that such alternatives will soon replace the battery cage, but it enlarges the possibility of a more general adoption of alternative systems in the future.

5.2 The Bugs Eat the Waste

In the first decade of this century, the municipality of *Enschede* was legally forced by the owner of the estate *Twickel* to purify the water of the *Twekkelerbeek*, a brook into which several sewers discharged.[54] It was decided to build a sewage treatment installation. The installation built is described in *De Ingenieur* (*The Engineer*) of 1923 by ir. Mos, the director of Municipal Works in *Enschede*. According to Mos, this installation was 'the first, and until now the only one of its kind, that has been built in the Netherlands.' Mos characterizes sewage treatment as a 'very important part of town-planning,' 'a new domain, which has been developed in ... England, the United States and Germany.'

The layout of the *Enschede* plant is given in Figure 5.1. The main parts of the plant are the so-called sedimentation tanks, in which the water is treated after it has gone through a grit and sand remover. The sedimentation tanks are shown in cross-section in Figure 5.2. Mos explains in his article why this kind of sedimentation tank has been chosen. He briefly describes the history of sedimentation tank development.

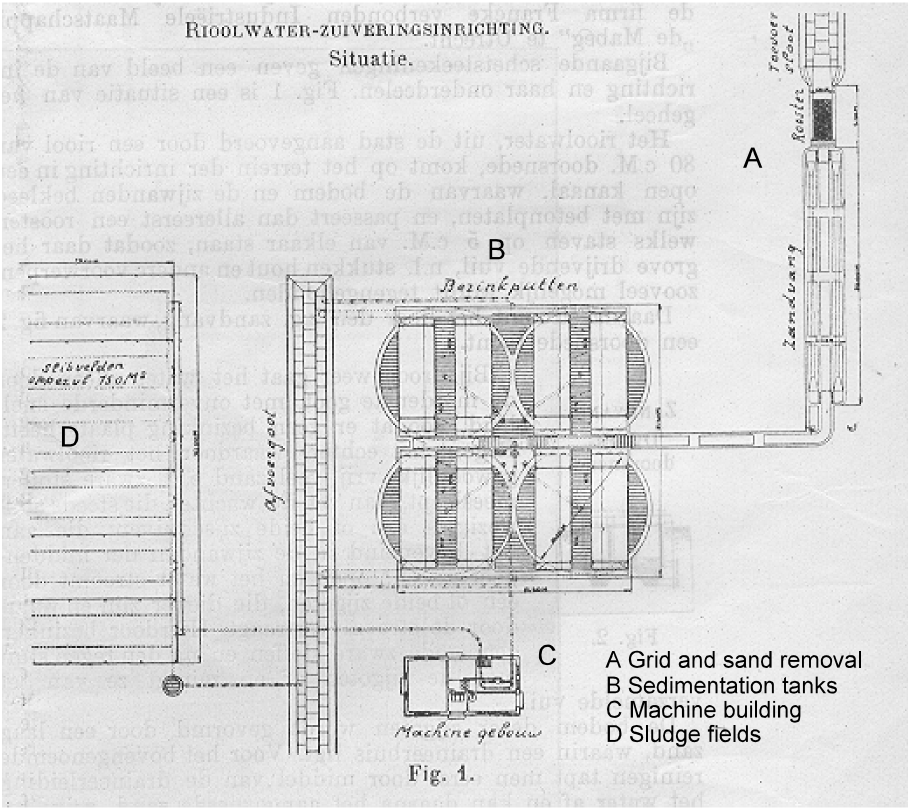


Figure 5.1 *Lay-out Enschede Plant (Reproduced from The Engineer 1923)*

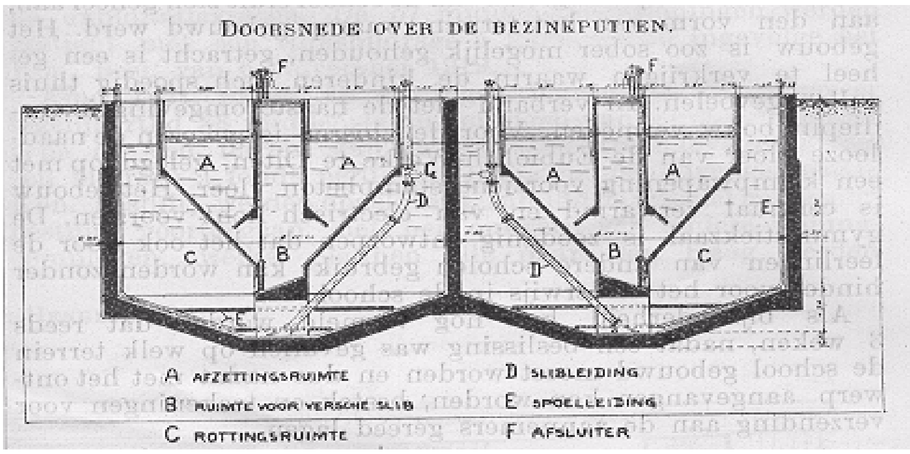


Figure 5.2 *Cross-section of Sedimentation Tanks (Reproduced from The Engineer 1923)*

A Sedimentation room
B Room for fresh sludge
C Putrefaction room
D Sludge pipe
E Flush pipe
F Fastener

He states that 'it has taken many experiments ... to determine the right shape of sedimentation tanks and the required flow of the waste water.' The problem then became 'the removal and treatment of the collected sludge.' An important step toward the solution of this problem was the development of the *Emscher Brunnen* or Imhoff tank, a two-story tank with a separate sedimentation and fermentation chamber. Mos comments on this system:

> *Compared with other mechanical treatment methods, a major advantage of this system is the simple and practical way in which the problem of sludge treatment and disposal is solved.*

But,

> *Meanwhile, even Emscher Brunnen have been repeatedly plagued by symptoms - especially the so-called 'acid' fermentation of the sludge - that compromises their proper functioning. The putrefaction of the sludge is unsatisfactory, often for unexplainable reasons ... The result is a nasty smell, while the required sludge sedimentation stops ... Therefore, several improvements to the Emscher Brunnen have been tried ... we believe, however, that the solution to the main problem, i.e. the prevention of the above mentioned 'acid' fermentation,' can only be found by a construction in which the fresh water and the fermentation chamber are separated as much as possible.*

Such a kind of construction had been realized by the German firm Carl Francke and was chosen by the municipality *Enschede*. *Enschede* ordered these so-called Francke Brunnen from a Dutch firm connected to the German firm Carl Francke, which realized them between 1920 and 1921.

The *Enschede* example reveals some characteristics of the early technological regime of sewage treatment plants. It shows that sewage treatment was in principle a municipal responsibility. Sewage treatment was seen as a part of 'town-planning' or more precisely as a continuation of the sewerage system. So, if sewage treatment was practiced, the design of treatment plants was the task of the (civil) engineers who designed the sewers too. The example further demonstrates that sewage treatment technology was mainly developed in countries like Germany, England and the United States and that Dutch engineers oriented themselves to these foreign developments.[55] Treatment technologies developed at the end of the 19th and in the beginning of this century in these countries included anaerobic tanks like Francke and Imhoff tanks and aerobic methods like trickling filters and the activated sludge process.[56]

Finally, and most importantly for this story, the *Enschede* example shows that at the beginning of this century sewage treatment was generally conceived as a mechanical or hydraulic problem. Typically, Mos calls the Imhoff and Francke tanks 'mechanical devices,' while these purification methods are partly mechanical-physical (sedimentation of the sludge) and partly biological (anaerobic fermentation

of the sludge). Telling is the fact that Mos looked for a purely mechanical solution to a problem, which is - emphatically in Mos' formulation as well - clearly in part a biological problem: the 'acid' fermentation of sludge. Oddly, the problem of 'acid' fermentation did not spur an investigation into the mechanisms and dynamics of the biological purification process. The solution was sought in another 'mechanical' device to separate the fermenting sludge from the 'fresh' water. This attitude was typical for the sewage treatment regime until at least the late fifties: 'the bugs eat the waste' as the saying went; what else was there to know?[57]
In the sixties and seventies, some microbiological researchers and engineers interested in topics like microbiology and biochemistry condemned this state of affairs and tried to enlarge the role of professions like microbiology in the sewage treatment regime. This initiated a process of transformation that I will describe below.

In this story, I focus on the growing role of microbiologists and biotechnological researchers in sewage treatment plant research, design and innovation. In doing so, I leave aside two related processes of transformation. The first related process of transformation is that toward a larger role of chemical disciplines like process engineering in sewage treatment plant design.[58] The second related process of transformation is that toward the formulation of new and more stringent effluent standards. This process started in reaction to the aggression of the existing regime, *i.e.* the pollution of surface waters.[59] In this story, I describe the increased stringency of effluent standards as a background development and will not focus on the underlying process of transformation.[a]

This story consists of three parts. I start with a brief description of the professions historically involved in sewage treatment plant design in the Netherlands. I then describe how microbiological researchers criticized the fact that microbiological insights were hardly used in sewage treatment plant design. We will see how they tried to achieve a role in the existing technological regime via the formulation of design parameters based on microbiological insights. In the final part, I discuss how biotechnological researchers subsequently tried to bring about a biotechnological approach to sewage treatment plant research and design.

5.2.1 Professions Historically Involved in Sewage Treatment[60]

People involved in sewage treatment come from several disciplines. Making a distinction between three kinds of activities in discussing the contribution of different disciplines to sewage treatment is useful:

a For microbiological and biotechnological researchers involved in the *research* and *design* of sewage treatment plants, this transformation was indeed a background development. They did not undertake attempts to change the requirements for sewage treatment. Nevertheless, changing functional requirements for sewage treatment plants enabled the involvement of microbiologists and biotechnologists.

- The assessment of water quality (of the receiving water and of the sewage) and the formulating of the required rate of treatment (effluent requirements). In this activity, bacteriologists, hydro-biologists and agricultural engineers were usually involved.

- The so-called ‘technological’ design of the sewage treatment plant. This includes the choice of treatment technology and the setting of the main parameters. In this activity initially people with a background in chemistry, agricultural engineering and - more rarely - civil engineering and microbiology were involved.[61] Such people were described with terms like ‘chemist-biologists’, ‘treatment specialists’ and ‘sanitary engineers.’ (Sanitary engineering evolved as a branch of civil engineering).

- The design of the civil-engineering, mechanical and electro-technical part of the plant. Here, civil engineers were initially usually involved. Sewage treatment plants were still rather simple and seen as a continuation of the sewerage system. Later, mechanical and electro-technical engineers began to play a more important role.

In this story, I focus on the kind of professions involved in the so-called *technological design* of sewage treatment plants. The technological design has not always been recognized as a separate design activity. The design of the treatment plant in *Enschede* is a case in point. This plant was designed as if it were a civil technical object.
An important step in the emancipation of the design of sewage treatment plants from the design of sewerage systems and the recognition of the technological design as a separate activity was the establishment of the Netherlands Institute for the Purification of Waste Water or RIZA in 1920.[62] The task of the institute was to help combat or prevent water pollution by carrying out research and experiments. The RIZA recruited a small number of chemists and agricultural engineers who became responsible for the technological design of sewage treatment plants. Their designs were mostly based on experience, rules of thumb and some rudimentary insights into the (biological) processes underlying sewage treatment.[63] Insights from microbiology and biochemistry were hardly used.
The meager role played by microbiology and biochemistry was not unique to the Netherlands and was related to the educational and professional backgrounds of the people involved in the technological design of sewage treatment plants. With a general term, these people can be called ‘sanitary engineers.’[64]
In 1935, the Royal Dutch Institute of Engineers, or the KIVI *(Koninklijk Instituut voor Ingenieurs)* established a Division for Sanitary Engineering that played an important role in the establishment of special courses in sanitary engineering in the Netherlands.[65] In 1950, it became possible to follow an academic course in sanitary engineering at the Technical College Delft (*Technische Hogeschool Delft)*. This course was a voluntary part of the curriculum of the fifth and last year of the School of Civil Engineering (*Weg- en Waterbouwkunde*). This course concerned such topics as (drinking) water supply, sewerage and sewage treatment. In 1968, civil sanitary

engineering became one of the main subjects of the curriculum of Civil Engineering at the Technical College Delft.[66] By then, it included topics like the design, the biology and the chemistry of sewage treatment.
At the Technical College Delft, civil sanitary engineering was, emphatically, not meant as a specialization of civil engineering. The school wanted to train generalists, who had to acquire specialist knowledge on the job. It was believed that such people would be best fit to direct design projects like the design of sewage treatment installations.
So, sanitary engineering as it was taught in Delft was a part of civil engineering. Sanitary engineers were in the first place trained as civil engineers, as generalists. Compared with other civil engineers they had more knowledge of the chemistry and biology of sewage treatment, but they had not a full training in these aspects. This was not deemed necessary. This attitude was not only typical for Delft, but also dominated the technological regime of sewage treatment plants until at least the seventies. It was this attitude against which people with a background in (micro)biology and interested in sewage treatment began to protest in the sixties and seventies.

5.2.2 The Use of (Microbiological) Parameters in the Design of Sewage Treatment Plants

A Plea for a Larger Role for Microbiology

In the sixties and seventies, the civil engineering attitude in sewage treatment was attacked by outsiders with a background or interest in microbiology. In 1962, Ross McKinney - 'an engineer who became a microbiologist in order to design better waste treatment systems'[67] - wrote the book *Microbiology for Sanitary Engineers*. The first sentences of this book were:

> *One of the most unusual aspects of sanitary engineering in the United States is the fact that the engineers responsible for making this country the most sanitary in the world do not have a real understanding of the microbiology of the very processes they design. Waste treatment plants which base their entire operations on the microorganisms within them have been designed for the past fifty years with almost no consideration for the biochemical reactions brought about by the various microorganisms.*[68]

A year later, the book *The Ecology of Waste Water Treatment* by Hawkes - a biologist by training - appeared. He made the same observation:

> *[A]ctivated sludge plants are designed and operated by engineers and chemists who, in many cases, have little or no biological training. Such workers often find themselves in charge of the design, construction or operation of biological oxidation plants and not fully equipped to create a suitable environment for, or control the activity of, the myriads of "workers" employed in the processes of purification.*[69]

Such complaints were also reflected in the Netherlands, although in a scanty measure. In 1973, ten years after the appearance of the aforementioned books, it was a graduate student from the Agricultural College Wageningen (*Landbouwhogeschool Wageningen*), who wrote in Dutch journal H_2O:

> *In the study of the processes playing a role in the artificial purification of waste water in activated sludge plants and trickling filters, biology has always been treated a little bit like a poor relation. ... We know much more about the physical and chemical processes playing a role in treatment processes than about the role of the various organisms in the processes. This is very odd, because, in the end, the organisms do the purifying.*[70]

Typically, the article from which this quotation comes, mainly reflected the complaints earlier made by Hawkes and others. I have not been able to trace a public discussion in the Netherlands on the role of disciplines such as microbiology in sewage treatment. Therefore, I focus on the work of McKinney and Hawkes.

Both Hawkes and McKinney complained about the meager role played by (micro)biological insights in sewage treatment plant design. However, they offered different interpretations of the causes for this flaw. Hawkes merely blamed the inadequate training of sanitary engineers and their misperception of the treatment process, while McKinney also blamed the fact that microbiologists had not translated their insights into practicable design heuristics and parameters.
Hawkes argued in his 1963 book that insights from (micro)biology will probably be neglected unless people responsible for the design and operation of sewage treatment plants would receive a basic training in biology. As he put it: 'Without some understanding of the biology of the process, the non-biologist may have difficulty in appreciating the biologist's contribution.'[71] According to Hawkes, the education of sanitary engineers was defective in this respect. This observation is also made by McKinney and is supported by an observer who in 1961 discussed the difficulty of offering adequate biological training to sanitary engineers at engineering institutions:

> *[T]he biology for the sanitary engineer might be handled by one man - but he should be a biologist with a deep interest in one of the areas of biology significant to sanitary engineering. Biology is one of the sciences inadequately covered in most engineering institutions. One of the ways in which this deficiency could be met, if time were available in the curriculum, is by sending the students over to the biology department. However, these courses are generally designed for students who will then take other, more advanced, courses later. For the engineer this course might be his first and last contact with the subject. This is why courses should be designed specifically for the sanitary engineer, particularly when given at the graduate level.*[72]

Specially designed courses were, however, expensive and not every university or college could afford them.[73] Given these problems, it is understandable why people

like Hawkes, who had received in-depth training in biology, complained about the deficient biological training of sanitary engineers.
The reason why sanitary engineers often had only received superficial biological training was not only practical, it was also related to the idea that civil (sanitary) engineers were to be generalists and had to learn the particularities of their later design tasks on the job. In the Netherlands, this idea was particularly vivid in Delft, where - as we have seen - sanitary engineering was initially explicitly *not* a specialization of civil engineering. Given this attitude, it is not amazing that at least for the early sanitary engineers sewage treatment plants were just another civil technical object to be designed.

McKinney agreed with Hawkes on the deficient biological training of sanitary engineers. As he put it: '[i]t is obvious that there is a need either to teach the microbiologist engineering or to teach the engineer microbiology.'[74] As this quotation already suggests, McKinney also blamed microbiological researchers for not understanding the engineering aspects of the design and operation of sewage treatment plants:

> *Some sanitary engineers feel that microbiology is for microbiologists and that the microbiologists should have told the engineers of the use of microorganisms. Unfortunately, the microbiologists who have wandered into this field do not understand the engineering aspects of treatment plant design and operation. Thus, the microbiologist has been unable to tell the sanitary engineer what is needed and the sanitary engineer has been unable to translate the microbiologists' work into practical design.*[75]

According to McKinney, the problem was not that insight in the relevant biological processes did not exist, but that this knowledge had not been translated into insights (parameters, heuristics) that could be used easily in the design and operation of treatment plants:

> *In the past thirty years there has been a tremendous amount of research on the fundamentals of the activated sludge process which the engineer has never made use of because the researchers never translated their results into practical terms which the engineer could understand. This vast storehouse of information has lain dormant like the pirate treasure of [g]old waiting for someone to uncover the key to its use in the field.*[76]

This problem goes back - according to McKinney - to the fact that there is a difference in the professional interests and knowledge of microbiologists and sanitary engineers. Microbiology traditionally dealt with the taxonomy and activity of microorganisms. Although already since the beginning of the century microbiological investigations into sewage treatment had taken place,[77] classical microbiology has not always been helpful for the design of sewage treatment plants. It had been concerned with pure cultures of microorganisms in concentrated substrates, whereas sewage treatment plants employ mixed cultures, often in diluted substrates.[78] Moreover, the biologists who were active in sewage treatment were mostly hydrobiologists or bacteriologists. Their activities were often confined to the evaluation of water quality and water quality management and did not include the design and operation of sewage treatment plants. According to McKinney these people did not have the proper training to design or operate sewage treatment plants:

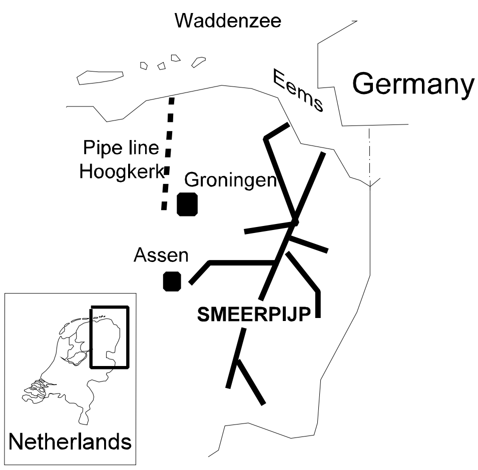
> *The bacteriologist who has received formal training primarily with pure culture in concentrated organic solutions finds waste disposal microbiology all but an entirely new science, with engineering and biochemistry of greater importance than conventional bacteriology.*[79]

The contribution microbiologists and other biologists *could* make to sewage treatment plant design then was not straightforward.[80] Moreover, for a long time, only some (micro)biologists were interested in making such a contribution. According to Hawkes, this changed with the growing ecological awareness in the sixties:

> *Until perhaps the early 1960's it was very rare to find a biologist involved, or indeed interested, in the design, operation and performance of ... [sewage treatment, IvdP] processes. Attitudes changed to some extent with the advent of the last decade when the general public became increasingly*

Box 5.2 *The Smeerpijp Affair*

At the end of the sixties, it was proposed to transport the waste water of the peat colonies related industry in the Northern Provinces (*Groningen* and parts of *Drente* and *Overijssel*) with a pipe line to the *Eems* estuary. Peat colonies related industries 'produce' a huge amount of waste water and their discharges had been a point of concern since the end of the nineteenth century. At the end of the 1960's, a committee proposed to solve the problem by building a *Smeerpijp.* It was estimated that the effluent of this pipe line would equal 24 million population equivalents during the campaign time of the peat colonies.



A number of environmental groups and well-known biologists protested against the *Smeerpijp*. The *Smeerpijp* affair also led to discussions within the Dutch Association for Waste Water Technology, the NVA. It was proposed that the NVA would speak out against the *Smeerpijp*, which did not happen. In parliament, questions were asked, and also Germany - the *Eems* estuary is at the border between the Netherlands and Germany - was critical about the plan. As a result, the Dutch Minister promised to commission biological research about the consequences of the proposed discharges. Only a part of the originally projected *Smeerpijp* was eventually built. Increasingly, the solution was sought in (partial) treatment or adapted production processes in the potato flour and card-board industry.

aware of the environment and its ecology. For the first time biologists found that their opinions were in demand and as a result many changed their purely academic studies to include applied biological topics as well ...[81]

In the Netherlands, this shift was exemplified by the so-called *Smeerpijp* affair in which biologists played an important role (see Box 5.2).[82]

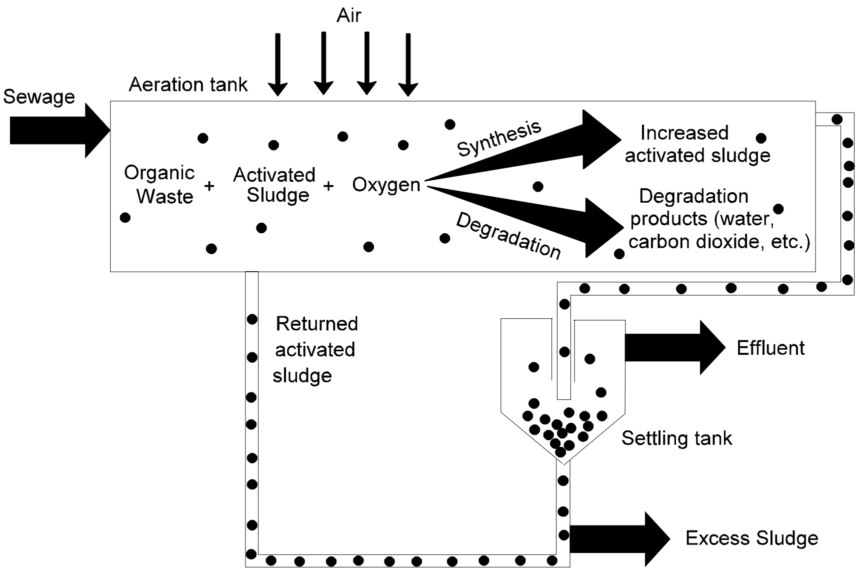
The Formulation of Parameters

From McKinney's - partly implicit - analysis it follows that if microbiology were to make a contribution to sewage treatment plant design, it had to translate microbiological insights into parameters, heuristics and rules of thumb that could be used easily in the design and operation of sewage plants. This strategy implied adding to existing technical models of sewage treatment plants or contributing to the development of new models.

Between the fifties and seventies, several international researchers indeed made such a contribution. I will not discuss these international contributions, but focus on how the international work on design parameters was received and further refined in the Netherlands, taking the work of professor Koot as a typical example.

In 1967, Koot published two articles on the design of sewage treatment plants in the Dutch journal *Water*.[83] At that time, Koot was assistant city engineer of the

Box 5.3 *The Activated Sludge Process*



Usually, sewage is first settled in a primary sedimentation tank before it is treated in the aeration tank. In the aeration tank, aeration plays a dual role. It supplies oxygen for the respiration of the microorganisms and it maintains the sludge in suspension. In the aeration tank, soluble materials are immediately digested by the microorganisms in the floc. Particulate and colloid materials have to be broken down extracellularly before they can be digested by the microorganisms. They are first adsorbed to the flocs, a process that is merely physical in nature.

Department of Public Works of the city of Amsterdam. Some years later, he became professor in Sanitary Engineering at the Technical College Delft and chairman of the NVA, the Dutch Association for Waste Water Technology. In his lectures at the Technical College, he discussed the same type of parameters and design fundamentals as can be found in his 1967 articles. In 1974, Koot published the book *Behandeling van afvalwater* ('Treatment of waste water') which was mainly based on his lectures and his 1967 articles.[84] Given his position as professor in Delft and chairman of the NVA, Koot's treatises must have been well-known among those active in sewage treatment plant design.

Table 5.1 *Parameters For the Design of Activated Sludge Plants (based on A.C.J. Koot, Behandeling van Afvalwater (Delft: Waltman, 1974), 159-218)*

A = Volumetric load [m^3/m^{3}*d]
B = BOD load [kg/m^{3}*d]
k = Sludge load [kg/kg*d]

T = retention period [d]
X = sludge age [d]
E = efficiency [%]

$$A=\frac{Q}{V}$$

$$T=\frac{V}{Q}=\frac{1}{A}$$

$$B=A*BOD_Q=\frac{Q*BOD_Q}{V}=\frac{n_{p.e.}*BOD_{p.e.}}{V}$$

$$E=\frac{B'}{B}$$

$$k=\frac{B}{G_a}=\frac{n_{p.e.}*BOD_{p.e.}}{V*G_a}$$

$$X=\frac{G_a}{G_w}$$

Q	[m^3/d]	Flow of used water
V	[m^3]	Total capacity of aeration tank
$(BOD)_Q$	[kg/m^3*d]	BOD feed in kg per m^3
$(BOD)_{p.e.}$	[kg/d]	BOD feed in kg per population equivalents (p.e.) per day
$n_{p.e.}$		Required capacity in population equivalents (p.e.)
G_a	[kg/m^3]	Weight, after drying, of the activated sludge in 1 m^3 of the aeration tank
G_w	[kg/m^3*d]	Weight, after drying, of the activated sludge withdrawn from the plant each day per m^3 of the aeration tank
B'	[kg/m^3*d]	BOD in kg removed each day per m^3 of the aeration tank

The BOD is equal to the quantity of oxygen needed to purify one liter of waste water. More exactly the BOD is defined as the quantity of oxygen removed from a mixture of one liter waste water with fresh water after 5 days in the dark at a temperature of 20 °C. This is the so called BOD_5^{20}. The waste caused by the population was mostly equaled to 54 gram BOD per population equivalent p.e. (in Dutch: *inwoner equivalent*) - one of the so-called Imhoff numbers - and the waste caused by industry was assessed by analyzing samples and then also translated in a number of p.e.'s.

Koot's book and his articles treat the basics of sewage treatment plant design and operation and give the most important parameters and rules of thumb that can be used in the design (and operation) of waste water treatment plants. He discusses various devices that play a role in sewage treatment like sedimentation tanks, trickling filters and activated sludge plants. I focus on the design rules for activated sludge plants (for the activated sludge process see Box 5.3).[85] The activated sludge process had been developed in the 1910's by two English chemists, Ardern and Lockett.[86] Between the 1940's and 1970's, Dutch researchers had developed two important variations to the activated sludge process, the Pasveer or Oxidation Ditch and the Carousel. Both were essentially very low-rated activated sludge plants.[87] Since the seventies, the activated sludge process and variations like the Oxidation Ditch and the Carousel have become the dominant sewage treatment plant design. Tables 5.1 and 5.2 summarize the major parameters and rules of thumb that Koot gives in relation to the design of activated sludge plants and especially those that are important for the dimensioning of the aeration tank.[88] One of the most important parameters in the design of activated sludge plants, according to Koot, is the sludge load. This is

> *[T]he ratio between the delivered food and the [activity of the, IvdP] microorganisms necessary for treatment ... Despite the inaccuracy, the sludge content or the sludge concentration is usually taken as indicative for the activity of the microorganisms ... As a measure for the delivered food the BOD-load B is usually taken.*[89]

Another important parameter defined by Koot is the sludge age, a measure for the mean retention time of the *sludge* in the aeration tank. The sludge age can be calculated by taking the ratio of the sludge concentration in the aeration tank and the sludge concentration of the wasted sludge. In a high-rated installation the sludge age is several hours; in an Oxidation Ditch, which is essentially a very low-rated activated sludge plant, it is several days.

While Koot was probably well aware of the biological nature of the processes taking place in an activated sludge plant, his approach mainly aimed at presenting a number of parameters and rules of thumb that would be helpful in the design and operation

Table 5.2 *Rules of Thumb to Design Activated Sludge Plants Given by Koot (based on A.C.J. Koot, Behandeling van Afvalwater (Delft: Waltman, 1974), 169)*

	High-rate	Low-rate	Oxidation ditch
Volumetric load (A)	some number of tens	3 - 6	0.25 - 0.33
BOD load (B)	3 or more	0.4 - 1	0.18 - 0.2
Sludge load (k)	1 or more	0.4 or less	0.05
Retention period (T)	less than a few hours	5 - 8 hours	60 - 72 hours
Efficiency (E)	less than 90%	90% or more	more than 95%

of such plants. Once such parameters have been defined and their required values have been set (see Table 5.2), one can, in principle, 'forget' about the underlying biochemical processes as the example in Table 5.3 shows.[90] Typically, the calculation made in Table 5.3 at no point refers to biological processes. The design parameters as it were blackbox the processes occurring in a sewage plant.
From a microbiological or biochemical point of view, on the other hand, the focus would be on the processes taking place in an activated sludge plant. From such a point of view, the biological processes in an activated sludge process are determined by conditions like the availability of nutrients, pH, toxicity, aeration, temperature and the relationship between the available food (nutrients) and the population of

Table 5.3 *Example of a Calculation*

With help of Table 5.2, the main dimensions for an activated sludge plant can easily be calculated. The example below is based on, but not completely similar to, examples given by Koot (see A.C.J. Koot, *Behandeling van Afvalwater* (Delft: Waltman, 1974), 195-196 and 295-296).

If the required capacity of the plant is 100.000 population equivalents (p.e.) and the mean use per p.e. is 150 [liter/day]; the mean flow of waste water (Q) is equal to 100,000 * 0.150 = 15.000 [m^3/d]. Since a population equivalent is held equal to a BOD-number ($BOD_{p.e.}$) of 54 gram oxygen per day before and 35 gram after sedimentation, for an installation with primary sedimentation the sludge load (k) is equal to:

$$k = \frac{n_{p.e.} * BOD_{p.e.}}{V * G_a} = \frac{100{,}000 * 35 * 10^{-3}}{V * G_a}$$

If a purification efficiency between 90% and 95% is required a sludge load of 0.25 can be chosen (see Table 5.2) and if G_a is taken to be 3 [kg/m^3] then the required volume (V) can be easily calculated:

$$V = \frac{n_{p.e.} * BOD_{p.e.}}{k * G_a} = \frac{100{,}000 * 35 * 10^{-3}}{0.25 * 3} = 4{,}667[m^3]$$

The volumetric loading (A) and the BOD loading (B) can now also be calculated:

$$A = \frac{Q}{V} = \frac{15{,}000}{4{,}667} = 3.21[\frac{m^3}{m^3 d}] \qquad B = \frac{n_{p.e.} * BOD_{p.e.}}{V} = \frac{100{,}000 * 35 * 10^{-3}}{4{,}667} = 0.75[\frac{kg}{m^3 d}]$$

These figures fit the rules of thumb for low-rated activated sludge plants as given in Table 5.2. In practice, the flow of waste water will vary from hour to hour. Since 15,000 [m^3/d] is approximately equal to 600 [m^3/h], we can equal Q_{max} to 2 times Q_{mean}, thus Q_{max} = 1,200 [m^3/h] and if we equal Q_{min} to half Q_{mean}, then Q_{min} = 300 [m^3/h]. When it rains the flow of waste water is even more, if we take Q_{rain} = 3 * Q_{max}, then Q_{rain} = 3600 [m^3/h]. We can now calculate the possible variations in, for example, the retention period.

The mean retention period is equal to: $T = \frac{V}{Q} = \frac{4{,}667}{600} = 7.8[h]$

The retention period at Q_{max} is equal to: $T = \frac{V}{Q} = \frac{4{,}667}{1{,}200} = 3.9[h]$

And the retention period when it rains is equal to: $T = \frac{V}{Q} = \frac{4{,}667}{3{,}600} = 1.3[h]$

microorganisms.[91] If the 'environmental' conditions for the biomass are satisfied, the activity and the purification capability of the microorganisms are mainly determined by the relation between the available food (f) and the population of microorganisms (m).[92] For this relation, two parameters are important that are also distinguished by Koot: the sludge load and the sludge age. In biological terms, the sludge load is equal to the ratio of food available in the aeration tank and the living biomass in the tank (k=f/m).[a] The sludge age is equal to the average age of the sludge floc in the system. The sludge age is important because the bacteria and other microorganisms in the sludge go through different phases of growth and in these different phases the structure and the activity of the flocs (types of dominant bacteria, age of various bacteria populations, etcetera) change, influencing the purification capability of the sludge.

If we compare the description of the activated sludge process and the relevant parameters given by Koot and the description given by, for example, Hawkes, who has a 'stronger' microbiological background, they clearly approach the subject from a different angle. Where Koot takes the design of treatment plants as starting point, (micro)biologists like Hawkes focus on the microbiological processes taking place in such plants.
Koot and Hawkes then interpret the *same* parameters in somewhat *different* ways. For Hawkes and other (micro)biologists, a parameter like sludge load (= f/m ratio) in the first place has a biological meaning, whereas Koot and other civil engineers interpret it merely in a constructional way. Despite these differences, they operationalize and calculate the parameter in the same way. So, it also has a common meaning for them.[93]
This has important consequences for the formulation and use of design parameters and, in particular, the relation between those two activities. It means that microbiologists and biochemists can contribute to the formulation of design parameters without bothering too much about the constructive aspects of sewage treatment plants. Sanitary engineers, on the other hand, can use the parameters without knowing the finesses of the underlying microbiological and biochemical processes. Parameters like sludge load then make it possible to translate microbiological insights into practical design tools. This was exactly the kind of translation so desperately needed according to McKinney.[94]

Use of Parameters in the Design Process

In the seventies, the use of parameters like sludge load became increasingly common. This transformation was facilitated by the fact that in the seventies many new engineers came to be employed by Water Boards and engineering firms.[95] These were sanitary engineering from the Technical College Delft where Koot was

a This is roughly the same ratio as Koot gives (see Table 5.1). Koot takes the BOD load (B) as measure for the delivered food (f) and the sludge content or concentration (G_a) as indicative for the active biomass (m). As Koot points out the latter is somewhat inaccurate because the sludge may contain dead matter. Moreover, the phase of growth in which the microorganisms are is also important.

professor, chemical engineers from a number of universities and agricultural engineers from the Agricultural College Wageningen. At the latter college, it had become possible to graduate in Water Treatment in 1962.[96] In contrast to sanitary engineering in Delft, this specialization did not focus on the constructive and engineering aspects of sewage treatment plant design, but on the underlying biochemical processes.[97]

The new engineers employed in the seventies were, as a rule, aware that designing sewage treatment plants meant designing a biochemical process and not simply designing a civil technical object. These people had some insight in biochemical processes because of earlier developments in the educational infrastructure with respect to sewage treatment. They came to be employed *in the seventies* due to developments in the use of sewage treatment plants in the Netherlands. In the sixties, the number of sewage treatment plants began to grow rapidly due to various kinds of subsidies that became available. In 1970, this trend was consolidated by the Dutch Pollution of Surface Waters Act or WVO (*Wet Verontreiniging Oppervlaktewateren*).[98] With this law new resources were generated to expand the number of treatment plants in the Netherlands further. Charges were levied based on the principle ‘the polluter pays’ and subsidiary schemes were raised to stimulate the building of treatment plants.

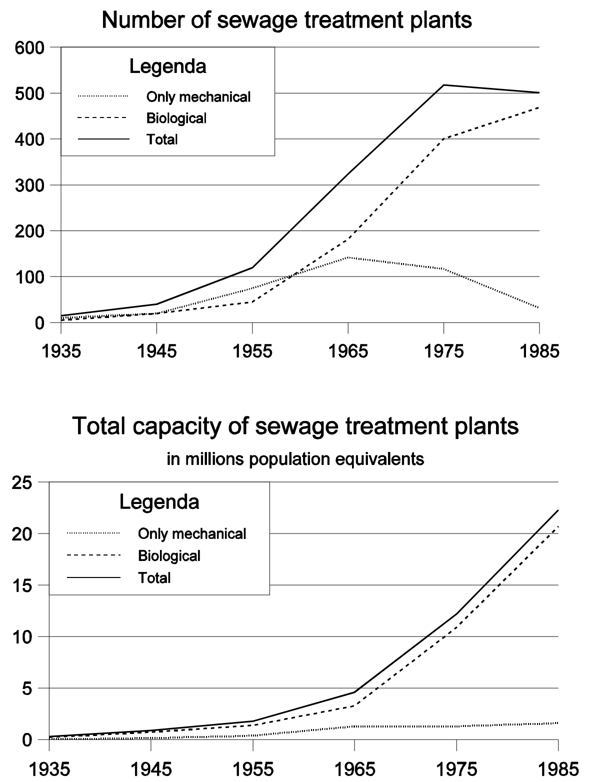


Figure 5.3 *Growth in Number and Total Capacity of Sewage Treatment Plants in the Netherlands*

After 1970, national policy plans were formulated with respect to sewage treatment and effluent standards.[99] This resulted not only in a growing number of treatment plants, but also in more stringent effluent standards. Increasingly, treatment plants began to employ not only 'mechanical' treatment[a] but also biological methods (see Figure 5.3).[100] In particular after 1970, it became standard practice to build sewage treatment plants employing at least a purely mechanical stage (including sedimentation) followed by treatment in an activated sludge plant.[101]

5.2.3 Toward a Biotechnological Design Approach?

We have now seen one way in which insights from microbiology - but also from biochemistry and process engineering - have come to play a role in the technological regime of sewage treatment plants, *i.e.* via the development and use of design parameters. The seventies and eighties have witnessed a further development of these and comparable design tools for sewage treatment plant design. Especially the development of so-called dynamic models should be mentioned briefly. While in the seventies, the relations between most of the important parameters were known for stationary circumstances, the relationship between parameters in dynamic, *i.e.*, non-stationary circumstances, was still obscure. Since the seventies research groups from all over the world have developed dynamic models.[102] Most of these models use, in one way or the other, the so-called Monod equation to model the growth of microorganisms. This microbiological equation was formulated by Monod in the forties. Apart from microbiology, the development of dynamic models was also based on disciplinary insights from biochemistry and process engineering.
Dynamic models are now sometimes used by engineering firms in the design of sewage treatment plants. Designers have, however, been cautious about their use, particularly the older generation of engineers. They stress that designing a sewage treatment plant is more than calculating the value of particular parameters with the help of a model.[103]

There are two reasons why parameters and later dynamic models were rather easily adopted as design tools for sewage treatment plants. One was that they fitted the evolving practice of designing sewage treatment plants as it was taught at engineering institutions and (subsequently) practiced at engineering firms and Water Boards. Both design parameters and dynamic models blackboxed their microbiological and biochemical meaning, which eased the adoption of such design tools by engineers with some insights in microbiology and biochemistry, but without a throughout understanding of these fields.
The other reason is the increased practicing of sewage treatment and the increasing stringency of effluent standards. In the seventies, this created a demand for new engineers, who often had some microbiological and biochemical insight in sewage treatment and had learned to use design parameters. Later, more stringent effluent

a The term 'mechanical' is somewhat misleading because it is often also used for anaerobic treatment methods which are partly biological in nature. However, in the jargon of the sewage treatment regime, biological treatment mostly means treatment by aerobic methods like trickling filters, conventional activated sludge tanks and later developed variants like the Pasveer Ditch and the Carousel.

requirements created a demand for design tools with which sewage treatment plants could be designed in a more sophisticated way. Parameters and models to some extent offered this possibility.

Design tools like parameters could thus rather easily be implemented in the evolving way of designing treatment plants. They changed the way of designing sewage treatment plants somewhat, but they did not amount to a radically different design approach.
Since the sixties, a plea has been made for what we would now call a *biotechnological* design approach. This approach takes the optimization of biochemical and microbial processes as point of departure. Choice of plant or reactor type should follow on the processes to be optimized. Such an approach would not take the activated sludge process as point of departure, as many existing design tools like dynamic models do. The acceptance of such a approach would transform the design of sewage treatment plants more fundamentally than the adoption of design tools like design parameters.

A Plea for a Biotechnological Approach

One of the first times that the idea of a biotechnological approach was articulated in the Dutch sewage treatment regime was probably in 1966. In that year, the Dutch chemist Peters wrote in the journal *Water*:

> *The increasingly overlapping physiology, chemistry and biology [of sewage and waste water treatment, IvdP] ... have led to remarkable results. A new area of science is ... coming into existence, i.e. waste water physiology. Like all natural science, waste water physiology has to rely on the experiment, that in this case must start with the output produced by living cells.*[104]

According to Peters, more attention had to be paid to insights from microbiology and biochemistry:

> *Knowledge has not yet been applied in the area of waste water technology. The metabolism of the cell and the ecological environment are coordinated by regulating mechanisms. By controlling the regulating mechanisms, reaching an enormous improvement in the workings of biological purification processes might be possible, accompanied with revolutionary changes in the traditional purification systems in use until now*.[105]

So, Peters pleaded for integrating insights from the traditionally distinct disciplines biochemistry, microbiology and process engineering to optimize the metabolistic processes in sewage treatment, possibly leading to radical new systems. In modern terms, Peters argued for a biotechnological approach.[106]

Internationally, the idea of biotechnology as an independent interdisciplinary field of research and application was for the first time fully articulated in the early sixties.[107] From then on, classes in biotechnology appeared on various curricula at the

universities; professional organizations were set up; biotechnological meetings were organized; governments started funding programs; firms increasingly became interested in the field.
In the broadest sense of the term, biotechnology refers to the manipulation of biological processes for human purposes, including genetic modification. In a more circumscribed sense, it is confined to the manipulation of (the metabolism of) living cells and enzymes for such purposes as the production of pharmaceuticals, industrial products and food, and the treatment of substances like sewage, waste and polluted soil. Until recently, most emphasis in the Netherlands was on industrial biotechnology; less attention was paid to environmental biotechnology, including sewage treatment. This especially holds for governmentally funded stimulation programs and the interests of firms.
Nevertheless, at some universities environmental biotechnological research on sewage treatment has been carried out since the early seventies. This includes the

Box 5.4 *Development of the UASB-Reactor and Other Alternative Reactor Types*

Anaerobic treatment technologies have been used in sewage and waste water treatment since the nineteenth century. Examples are the septic tank, the Imhoff tank and the clarigester. These technologies are hardly used for sewage treatment anymore. Between the forties and seventies, internationally several new anaerobic processes were developed, but these did not attract much attention in the Netherlands.
In 1971, Lettinga of the Agricultural College in Wageningen started experiments with anaerobic treatment of waste water. In cooperation with the sugar producing firm CSM, and later the Technical College Delft, the so-called UASB (Upflow Anaerobic Sludge Blanket)-reactor was developed, tested and upscaled. Apart from the researchers from Wageningen, also researchers from the section Biochemical reactors in Delft were involved in the upscaling of the UASB-reactor.
The UASB-reactor has some advantages as well as disadvantages compared with aerobic treatment processes like the activated sludge process. Advantages of the reactor are less production of (excess) sludge, less consumption of energy (lower costs), the production of the energy-carrier methane, and the fact that the process can handle large loads of waste water. Disadvantages are the incomplete treatment of the waste water, the long time required to start the reactor and the vulnerability to toxic substances. The UASB-reactor has mainly been used by agro-industrial firms as method to pretreat their waste water before discharging to the sewerage system. Agro-industrial firms often produce large amounts of concentrated organic waste, for which the UASB-reactor is particularly appropriate
Since 1976, researchers of the Agricultural College Wageningen have investigated the use of the UASB-reactor for the treatment of sewage. Mostly, the results have been unsatisfactory. In 1986, about thirty UASB-reactors were in use to treat industrial waste water. Meanwhile, also a number of other reactor types have been developed. With financial support from the Dutch government, the Dutch biotechnological firm Gist-Brocades has developed a reactor concept in which the microorganisms are attached to an inert fluidized support medium like sand. This so-called Upflow Fluidized Bed (UFB)-reactor has been used by Gist-Brocades since 1984. Also other reactor concepts have been developed like the fixed film reactor, in which the microorganisms are attached to a fixed carrier and reactors using membranes.
New reactors for the treatment of industrial waste water were usually developed in close cooperation between industrial users and universities. In several cases, industrial firms have set up their own research teams and patented the developed reactor concepts as a way to earn back their investments. The basic knowledge of anaerobic treatment is, nevertheless, free. There are, at the moment, two major firms producing (anaerobic) biological reactors for industrial waste water treatment: Paques and Biothane; the later is an independent spin-off company of Gist-Brocades.

Department Water Treatment at the Agricultural College Wageningen (later renamed as Environmental Engineering) and the Section Biochemical Reactors (School of Chemical Engineering) at the Technical College Delft. The latter section was initially mainly active in biochemical reactor research for industrial production. Later it became active in (industrial) waste water treatment.[108] Around 1984, the Section Biochemical Reactors was replaced by the new Department Biochemical Engineering *(Bioprocestechnologie)*. At the same time, a Department Microbiology and Enzymology was established. Both departments came to work closely together with biotechnological researchers from the universities of Leiden and Wageningen.[109]

Researchers from Wageningen and Delft have proposed and developed several treatment technologies and reactors that radically differ from the activated sludge process. Many of these alternative technologies are based on anaerobic treatment and were initially developed for industrial waste water treatment (see Box 5.4).[110] Recently, researchers from both Wageningen and Delft have argued for the application of these treatment technologies for sewage treatment. In 1989, Professor Lettinga of the Department of Environmental Engineering in Wageningen argued that future sewage treatment technologies should be based on the environmentally more sound anaerobic biological processes, as realized, for example, in the UASB-reactor.[111] Professor Heijnen of the Department of Biochemical Engineering in Delft has stated that the future problems facing sewage treatment require the use of more compact reactors based on, for example, a sludge-on-carrier concept.[112]
The proposals of Lettinga and Heijnen have not met with general enthusiasm in the sewage treatment regime. The reaction of professor Van der Graaf of the Section Sanitary Engineering (School of Civil Engineering) in Delft and head of the engineering firm *Witteveen + Bos* is typical. Recently, he has stated that the solutions proposed by Lettinga and Heijnen do not solve the (future) problems facing sewage treatment. Instead, he believes that future systems should be based on extensions of the conventional low-rated activated sludge process.[113]

Innovations in Sewage Treatment

Despite the rejection of some ideas of biotechnological researchers by people like Van der Graaf, more stringent effluent standards offered biotechnological researchers some opportunity to contribute to innovations in sewage treatment and to effectuate a biotechnological approach.
Until the seventies, waste water treatment aimed particularly at removal of organic waste.[114] Since then, also requirements for other substances have been formulated. At the end of the seventies, standards for so-called Kjeldahl-Nitrogen (Kj-N) were formulated, implying some degree of nitrification to be reached at each sewage treatment plant. In the nineties, phosphate and nitrogen removal became compulsory.[115] Especially the latter has offered biotechnological researchers an opportunity to contribute to innovations in sewage treatment plant design. Before I discuss this contribution, it is useful to describe briefly the existing innovation pattern of the regime of sewage treatment plants.

Innovations in sewage treatment are usually developed in response to the (changing) functional requirements of the bodies responsible for sewage treatment. Partly, these requirements derive from missions formulated by the central government laid down in central policy documents and policy plans for the abatement of the pollution of surface waters. These plans have to be carried out by the regional water administrators responsible for sewage treatment.[116]
Research in sewage treatment is usually practice-oriented. In the early sixties, a research infrastructure for sewage treatment began to establish. Research began to be carried out at the Technical College Delft and at the Agricultural College in Wageningen.[117] This research mostly had a short-term focus, was practice-oriented and was led by the functional requirements of users.
In the seventies, when provinces, Water Boards and treatment boards took over the responsibility for sewage treatment from municipalities, the Foundation for Applied Waste Water Research or STORA (*Stichting Toegepast Onderzoek Reiniging Afvalwater*) was established.[118] STORA coordinates the research of the bodies responsible for sewage treatment. Research funded by the STORA is usually carried out by engineering consultants, the Netherlands Organization for Applied Scientific Research (TNO) and universities. Until recently, most of the research was directed at solving actual problems in sewage treatment. The STORA has become *the* authority on the feasibility of new treatment technologies.[119] New technologies that have not been approved by STORA researchers are usually seen as unproven and, so, are seldom proposed by consulting engineers or accepted by Water Boards.[120] Therefore, the STORA plays an important role in the acceptance of new technologies and new design approaches proposed by biotechnological researchers. I will now look how this turned out for innovations with respect to nitrogen and phosphate removal.

Generally speaking, nitrogen and phosphate removal has been achieved by three types of measures:

- closer process control;
- minor modifications of existing (activated sludge) plants and
- adding treatment stages.

The first strategy is closely related to the earlier described developments in dynamic models. Such dynamic models can also be used for process control.[121] This requires on-line measurement of particular parameters during operating. Apparatus for such measurements is usually expensive. Moreover, effective control often requires extra operator skills. Therefore, process control is not easy to implement and, henceforth, not yet a general rule.

The second strategy, minor adaptations of existing plants, can imply the birth of a biotechnological design approach, in which optimal conditions for different microorganisms at different locations in a treatment plant are created.[122] An example is nitrogen removal.[123] Nitrogen removal can, among other methods, be achieved by the double process of nitrification and denitrification. These processes were discovered in the nineteenth century by microbiologists. They did not attract much

attention among sanitary engineers until the fifties of this century. Since the sixties, frequently publications have appeared on the application of the processes of nitrification and denitrification in sewage treatment.
Nitrification requires a certain sludge age, since nitrifying bacteria tend, depending on the temperature, to grow slower than bacteria digesting the organic waste. This means that nitrification can be achieved in almost every low-rated activated sludge - plant. Denitrification on the other hand requires anoxic conditions, *i.e.* low dissolved oxygen conditions. This can be reached by building an anoxic zone in a sewage plant. Such an approach might be called biotechnological because it implies the design of a treatment *process* and is based on microbiological and biochemical insight in the relevant microorganisms and their metabolism.

The third strategy - adding treatment stages - has often been preferred by Water Boards for treatment plants at which more stringent effluent standards could not be met by the first two strategies. In such cases, adding a treatment stage is often more cost-effective than building a new plant.
Biotechnological researchers may play a role in the development of additional treatment stages.[124] However, within the existing regime, the involvement of biotechnological researchers was not generally felt as a necessary or logical step following the tightening of effluent standards. The biotechnological researchers themselves had to prove their relevance. A typical example is the history of biological phosphate removal.[125]
Since the early seventies, various methods to remove phosphate by biological means have been developed in countries like the USA and South-Africa.[126] In the Netherlands, research on biological phosphate removal started in the mid seventies at the Agricultural College Wageningen. According to its proponents, biological phosphate removal helps to overcome or reduce some disadvantages of chemical methods for phosphate removal, like the need to use expensive and polluting chemicals, the production of excess sludge and interference with the process of nitrification.[127]
For a long time, biological methods were seen as ‘unproven’ within the Dutch sewage treatment regime.[128] An important reason was that in 1988 a STORA report was skeptical about the possibilities of biological phosphate removal. When later STORA reports began to sketch a more positive picture, the method became more popular.

As the above shows, the philosophy of meeting more stringent standards is essentially based on adding treatment stages to existing plants, combined with some minor modifications, including closer process control, of the conventional activated sludge process. Within this approach, a contribution of biotechnological researchers is to some extent accepted. However, new reactors concepts or treatment technologies are hardly considered to meet more stringent effluent standards.[129]
Water Boards are mainly interested in technologies that can be implemented at existing plants on a cost-effective basis. They do not want to destroy sunk investments in existing treatment plants.
For new plants, new reactor concepts are hardly considered too. Most new sewage treatment plants are based on the conventional activated sludge process.[130] -

Alternatives like the UASB-reactor and the sludge-on-carrier concept are not (yet) accepted as feasible for sewage treatment by engineering firms and Water Boards.[131]

At the moment, some developments are underway in the regime of sewage treatment plants that may offer biotechnological researchers further opportunities to enlarge their role. Within the regime, attention is growing for several problems with respect to sewage treatment. The removal of heavy metals and micro-pollutants from sewage is expected to become compulsory in the future.[132] Design criteria related to noise, stench and energy consumption will become more important. The production and treatment of excess sludge may become a critical problem, since *untreated* excess sludge is often no longer seen as an agricultural fertilizer, but - due to the presence of heavy metals and other substances - as a toxic waste. Compactness of plants will probably become more important. Eventually, the striving for sustainable development may urge the reuse of raw materials and the regeneration of energy (methane), possibly implying radical new ways of treating sewage.
These expected trends have also led to a somewhat different attitude to long-term research. In 1988, the RIZA and STORA started the research program *RWZI 2000*.[133] This program not only aims at the development of new technologies to meet more stringent effluent standards but also at such goals as lower treatment costs, compacter installations requiring less space, reuse of raw materials and environmentally more sound treatment methods. The program is to fund 10 million guilders of research into the future treatment of sewage and sewage sludge. In both lines, three types of research are carried out: evaluation of technologies used in foreign countries; research at pilot plants and full-scale installations and fundamental research. The program thus creates funding for fundamental research directed at solving long-term problems and for the development of new reactor concepts.[134] This creates new opportunities for biotechnological researchers to enlarge their role in the technological regime of sewage treatment plants.

5.3 Discussion and Conclusion

The processes of transformation studied in this chapter set off in different ways. In the chicken husbandry story, a process of transformation was brought about in reaction to the aggression of the existing technological regime. In the case of sewage treatment plants, it was a demand upon the environment that initiated the process of transformation. Below, I will first discuss how these mechanisms worked out. Then I will focus on how the studied processes of transformation were enabled and constrained by the existing innovation pattern.

In the case of chicken husbandry systems, animal welfare groups made manifest the aggression of the existing regime by connecting particular secondary effects of this regime to a neglect of animal welfare. They criticized the fact that chicken husbandry design was guided by considerations of efficiency instead of considerations of animal welfare. They insisted on animal welfare as a new or additional guiding principle.

In the Netherlands, the critique of the existing guiding principle was in some respects successful. The public was quickly persuaded that animals suffered unnecessarily in battery cages. Governments felt obliged to take measures with regard to animal welfare in laying systems. Ethologists translated the guiding principle ‘animal welfare’ into more detailed requirements and heuristics. These design heuristics came to direct the search for alternative systems. The heuristics for alternative housing systems were reinforced by legal norms for alternative eggs, like the *Landbouwbesluit Scharreleieren*. Such legal norms defined in what respects scratching systems are more benign for animals than laying batteries. So, these heuristics became more compelling, the more people supported the stipulated legal rules by buying scratching eggs. In short, at least some actions of some actors became coordinated by the guiding principle animal welfare.

The battery cage story shows a third route for the feedback of secondary effects to a technological regime besides the routes of regulation and user pressure. This third route can be characterized as delegitimation. Animal right groups tried to feed back a secondary effect of the regime of chicken husbandry systems by connecting the occurrence of this effect to the neglect of generally held humane values. They hoped that this delegitimation would be so effective that actors within the regime would start to behave in a different way and would undertake attempts to forestall the particular secondary effect in the future.

The route of delegitimation may be effective in both a direct and an indirect way. In a direct way, it would amount to the establishment of a new guiding principle. This means that the actors involved would start to legitimize their behavior in terms of a new principle and that their day-to-day practices would be guided by this guiding principle or principles derived from it.

In an indirect way, delegitimation can initiate the two other routes for the feedback of secondary effects: regulation and user pressure. In that case, delegitimation brings regulators like the government and users into a position in which they are more willing to undertake action against an existing technological regime. This happened in the chicken husbandry story. Actors like governments and egg consumers, to some extent, changed their behavior under influence of the actions of animal welfare groups. This, in turn, resulted in the routes of regulation and user pressure. So, delegitimation functioned as a strategic detour, a delegitimation detour, that initiated the routes of user pressure and regulation.

In the case of sewage treatment plants, the process of transformation started as a demand of the existing technological regime upon microbiologists, biochemists and, later, biotechnological researchers. This was not an explicit demand. Microbiologists and biotechnological researchers, outsiders to the existing regime, made manifest this demand. They argued that they could make a contribution to the design of sewage treatment plant and, so, should play a role in the existing technological regime. They could do so because a situation existed in which particular (technological) problems in the regime could not be solved, at least not immediately or in an optimal way.

In this sense, the involvement of ethologists in the regime of chicken husbandry systems was also based on a demand. They had to offer knowledge on the basis of which the guiding principle or design criterion 'animal welfare' could be translated into more specific requirements. On the basis of this contribution, they acquired a more central role in the technological regime of chicken husbandry systems.

This chapter shows three ways in which outsider professionals may acquire a structural role in technological regimes due to a demand upon the environment: 1) with respect to operationalization of (new) design criteria or requirements, 2) with respect to design tools like parameters and technical models and 3) with respect to new design approaches.

The first route is most visible in the chicken husbandry. A demand upon ethologists was made to translate the general striving for animal welfare into more concrete design criteria and requirements. This role of ethologists was accepted within the regime as far as animal welfare was accepted as new guiding principle or design criterion and as far as ethologists could formulate concrete requirements for animal welfare laws and for the design of welfare-augmenting husbandry systems.

The route of design tools was most apparent in the first part of the sewage treatment story. This route was facilitated by the fact that the parameters for sewage treatment plant design developed by microbiologists and other researchers could be implemented in the evolving way of designing sewage treatment plants. The implementation of new design tools was further enabled by the tightening of functional requirements (effluent standards). Changing requirements ease the formulation of new design tools by marginal professionals if new requirements make the existing design tools insufficient. This is particularly so in regimes with a user-driven innovation pattern because in such regimes innovation, as rule, follows on functional requirements of users.

The third route for the inclusion of new professionals is that of a new design approach. We saw this route in the second part of the sewage treatment story. This route is distinct from the other two routes, in the sense that it implies a (complete) new way of designing artefacts in a technological regime. Of course, new design requirements and new design tools will also change the way of designing in a technological regime, but a new design approach can do so in a more far-reaching way because it may allocate new roles to already involved actors or create roles for professionals not yet involved. Once such a new design approach becomes generally accepted within a technological regime, a more permanent or even central role for initially outsider or marginal professionals may become more legitimate. The new professionals no longer have to prove in individual cases that they can make a contribution to the operationalization of design criteria or the development of design tools, but are recognized as full members of the technological regime. In the case studied, the effectuation of a new biotechnological design approach was not completely successful.

In what ways were the processes of transformation studied in this chapter enabled and constrained by the user-driven innovation pattern? In a user-driven innovation pattern, innovations usually start with new functional requirements of users. This is both an opportunity and constraint for processes of transformation. It is an opportunity because a transformation of the existing technological regime can be achieved via changing the functional requirements of users. In the chicken husbandry story, we saw attempts by outsiders to change the functional requirements of users. This was only partly successful. Although poultry farmers were sensitive to the ideological critique on the battery cage, they felt that posing different functional requirements, in which efficiency would be less predominant and animal welfare more important, would jeopardize their position on the egg market. They considered such economic risks unacceptable. Apparently, they were convinced that alternative welfare-augmenting systems would bring unacceptable tradeoffs for them in terms of efficiency. Further, they were convinced that consumers were not prepared to pay more for alternative eggs.

In the sewage treatment story, outsiders like microbiologists and biotechnological researchers did not undertake attempts to change functional requirements. Nevertheless, the fact that effluent standards became more stringent, independent from the studied processes of transformation, enabled a larger role of microbiologists and biotechnological researchers. More stringent effluent standards created new engineering problems and a demand for new design tools. Here, microbiologists and biotechnological researchers had something to offer and so could acquire a role in the technological regime. However, their contribution was only accepted as far as they could show to contribute to meeting more stringent effluent standards. So, the user-driven innovation pattern constrained the involvement of new (biotechnological) professionals, in the sense that their contribution was accepted as far as it could be useful for meeting existing functional requirements and not as a contribution to possible future requirements. (Although, this situation has recently changed somewhat).

The above suggests that the user-driven innovation pattern is particularly constraining for processes of transformation because users may resist specific transformations. This is, however, not exclusive to regimes with a user-driven innovation pattern. Resistance of users may constrain processes of transformation in any technological regime.[135] It is therefore useful to make a comparison with the other innovation patterns to reveal in what specific ways the user-driven innovation pattern constrain processes of transformation. In particular, it is useful to compare the user-driven innovation pattern with the supplier-dependent and R&D-dependent innovation pattern because in these two patterns innovations do not start with new functions, but with new technical configurations. (The mission-oriented innovation pattern is in this respect comparable to the user-driven innovation pattern because it starts with new functions defined in the forms of (new) missions. See further Chapter 6.)

In technological regimes with either a supplier-dependent or an R&D-dependent innovation pattern, R&D and innovation do not directly take place in response to (new) functional requirements of users. Of course, functional requirements play a role, but they are often not as guiding as in the case of a user-driven innovation pattern (or mission-oriented innovation pattern), or are only so in the later stages of development of technical alternatives. In the supplier-dependent and R&D-dependent innovation pattern, the development of technical alternatives and their acceptance by users are distinct activities. So, room exists to think out and develop technical alternatives independent from the acceptance of such alternatives by users.

Only at a later stage, when the products have been further developed and refined, users have to be convinced or regulation has to be issued.
The proactive development of technical alternatives is more difficult in a user-driven innovation pattern because individual users often have a short-term perspective and because the role of suppliers and researchers respectively is supportive rather than innovative. In the cases we observed that most research activities carried out by the *Spelderholt* and the STORA had a short-term focus, were practice-oriented and guided by the functional requirements of users. In the chicken husbandry story, research on alternative systems only started when governments paid for it or proposed to ban the battery cage, as in Switzerland. Development of technical alternatives thus took place through the route of regulation and hardly proactively, *i.e.* based on more diffuse expectations about future developments as in the cases in Chapter 4. In the sewage treatment story as well, we saw little proactive development of technical alternatives. STORA research merely responded to existing functional requirements. Recently, however, the room for long-term research has widened allowing for the development of technical alternatives in anticipation of future trends. This shift is not only related to specific (expected) problems in sewage treatment, but also to the fact that this technological regime has mission-oriented characteristics. Effluent requirements for individual sewage treatment plans partly derive from national and regional plans for water pollution. The actors involved in the formulation and implementation of such missions, and the STORA, are active at the global level of the technological regime. More than individual users, they will have an eye for long-term developments and developments outside the technological regime. This will further the proactive development of technical alternatives.
Still, in my cases, the user-driven innovation pattern constrained the development of technical alternatives that did not directly derive from functional requirements of users. Instead, it created a lock-in in trajectories of technological development defined by the functional requirements of users, or by a more encompassing guiding principle like 'efficiency,' as in the case of battery cages.
In the cases, we see several ways in which the constraints for the development of technical alternatives inherent in the user-driven innovation pattern can be circumvented. In the chicken husbandry story, technical alternatives were initially developed on the initiative of governments or in response to government regulation in countries like Switzerland where the battery cage was banned. In the Netherlands, the absence of users in the development process not only constrained the development of alternative systems but also their acceptance. The fact that the Dutch government saw the development of technological alternatives as a step toward a ban of the battery cage gave poultry farmers a strategic motive to resist alternative systems like the aviary. They might have opposed the aviary anyway given its tradeoffs in terms of efficiency (production price per egg) and the economic risks that this tradeoff according to the farmers introduced. However, the way in which alternative systems were developed led to growing antagonism between the government and poultry farmers and might have blocked the further development and optimization of alternative systems like the aviary, if the route of user pressure had not offered 'a way out.' This route showed that there was a market for alternative eggs and, hence, for welfare-augmenting systems. In this way, protected

spaces for further development and optimization of alternative systems were created. The creation of these protected spaces was enabled by the user-driven innovation pattern. As far as outsiders succeeded, via the sales of alternative eggs, in creating new functional requirements for users in specific market-niches, this also created room for the development and optimization of alternative systems. This was the case because in a user-driven innovation pattern, the development and optimization of alternative systems starts in response to, and in interaction with, the expression of functional requirements by users.

In the sewage treatment story, the related regime of industrial waste water treatment was used as a protected space to develop and optimize biotechnological treatment reactors. In this regime, somewhat different functional requirements were posed for which biotechnological reactors were more apt. Typically, biotechnological reactors were mainly developed for, and together with, industrial clients with expertise in the field of (chemical) process technology or biotechnology.

In both cases, the technical alternatives developed in protected spaces were hardly accepted in the existing technological regimes. In the case of battery cages, the systems were only in a scanty measure purchased by poultry farmers. In the case of sewage treatment, technical agenda building in the STORA played an important role in the selection of technical alternatives. STORA researchers only to some extent conceived biotechnological systems as proven. This constrained the acceptance of alternative systems by Water Boards and engineering firms. Still, in both cases, the fact that alternatives are available put some pressure on the existing technological regimes to improve their products.

Notes to Chapter 5

1 Large parts of the case description below appeared in I. van de Poel, 'Why are Chickens Housed in Battery Cages?,' in C. Disco & B. van der Meulen (eds.), *Constructing Sociotechnical Order* (Berlin: Walter de Gruyter, 1998) and in I. van de Poel & C. Disco, 'Influencing technology; design worlds and their legitimacy,' in J. Perrin & D. Vinck (eds.), *The role of design in the shaping of technology* (Proceedings from the COST A3 and COST A4 workshop Lyon, France, 3 and 4 February 1995) (Luxembourg: Office for Official Publications of the European Communities, 1996), 93-130. See also I. van de Poel, 'De Wereld van de legbatterij,' *Kennis en Methode*, XVIII(1994)4 (1994), 315-340.

2 *Dutch poultry farming world-wide* (The Hague: Ministry of Agriculture, Nature Management and Fisheries, 1992), 6.

3 *Lekker Dier,* information brochure on the bio-industry, 1985, my translation.

4 For a history of Dutch poultry farmers see E.H. Ketelaars, *Historie van de Nederlandse Pluimveehouderij* (Barneveld: BDU, 1992). The development and the introduction of the battery cage in Dutch poultry farming is described in more detail in Appendix 3.

5 Poultry research is also done at several Dutch universities, preeminently the Agricultural University at Wageningen and the Veterinary Faculty at the University of Utrecht.

6 *Publications Pluimveehouderij 1990*, 2-3; *Pluimveehouderij*, 22 May 1992, 20-23; Ketelaars, *Op. cit.*, 48-51. Recently also themes like animal welfare, biotechnology and environmental issues have been placed on the agenda.

7 R. Harrison, *Animal Machines; The New Factory Farming Industry* (London: Vincent Stuart, 1964), 2.

8 *Ibid.*, 4.

9 *Ibid.*, 58.

10 Ketelaars, *Op. cit.*, 242-243.

11 The description below is mainly based on T. Dekker, *Scharrelprodukten: Richtlijnen, controle, omzet en promotie* (Den Haag: Nederlandse Vereniging tot Bescherming van dieren, 1991).

12 The Dutch verb 'scharrelen' means something like 'messing about' or 'scratching.' The later term is used as translation by the *Dierenbescherming* and will be used here too.

13 This type of chicken housing is also sometimes denoted as 'deep litter houses with slats.'

14 *Pluimveehouderij,* 26 April, 1991, 4.

15 At this moment there are also other types of eggs that promote chicken welfare (besides scratching eggs) on the consumer market, like eggs from aviaries and eggs from free range farms (where the chickens are also allowed outdoors). These different types of eggs are also legally protected, being controlled by the *Stichting Nederlands Eiercontrole Bureau*.

16 Some initiatives are now undertaken to change this. In 1995, Calvé, a large producer of mayonnaise, introduced a mayonnaise made with scratching eggs, and distinguishable as such, onto the market (*Dier*, 76(1996)2, 30-31).

17 *Agrarisch Dagblad,* 8 November, 1990, my translation.

18 D.G.M. Wood-Gush, 'History and development of poultry ethology,' *Poultry*, April/May 1988 (1988), 8-9. Ethological research on chickens was already being carried out in the 19th century. In 1873 Spalding published the first ethological study on chickens.

19 P. Schenk, 'Het nuttige dier,' in M.B.H. Visser & F.J. Grommers (eds.), *Dier of Ding, objectivering van dieren* (Wageningen: Pudoc, 1988), 31-50. The number of institutions doing ethological research on animal welfare rose world-wide from 6 immediately after World War Two to about 30 at the end of the eighties (Wood-Gush, *Op. cit.*). In the Netherlands the number of ethologists active primarily in animal welfare rose from 5 in 1972 to 12 in 1988 (A.R. Kuit, D.A. Ehlhardt and H.J. Blokhuis, *Alternative improved housing systems for poultry* (Beekbergen: Ministry of Agriculture and Fisheries of the Netherlands, Directorate of Agricultural Research, 1989), Proceedings of a seminar in the community programme for the co-ordination of agricultural research, held at the Spelderholt Centre for Poultry Research and Extension, 17 and 18 May, 1988.)

20 Schenk, *Op. cit*. spells out this argument.

21 This box is based on M.S. Dawkins, 'Battery hens name their price: consumer demand theory and the measurement of ethological 'needs',' *Animal Behaviour*, 31(1983)4, 1195-1205; Schenk, *op. cit*.; H. Stern, 'Familienkrach der Verhaltensforscher,' *Der Spiegel*, 32 (1980), 50-58; R. Wegner, 'Poultry Welfare - problems and research to solve them,' *World's Poultry Science Journal*, 46(1990)1, 19-30; Studiecommissie Intensieve Veehouderij, 'Legbatterijen' (Derde Rapport van de Studiecommissie Intensieve Veehouderij, ingesteld door de Nederlandse Vereniging tot Bescherming van Dieren: 1975); *Agrarisch Dagblad*, 8 November 1990; *Pluimveehouderij*, 12 July 1991, 8-9; *New Scientist*, 22 January 1994, 28-31; *De Volkskrant*, 19 June, 1993.

22 Cited in R. Harrison, 'Case study: farm animals,' in R.J. Berry (ed.), *Environmental dilemmas: ethics and decisions* (London: Chapman & Hall, 1993), 118-135.

23 Cited in *Ibid.*.

24 Cited in *Ibid.*, 120.

25 Kuit *et al.*, *Op. cit.*.

26 Harrison, *Op. cit. 1993*. See also Study Commission on Intensive Livestock Farming, 'Alternatives for the battery cage system for laying hens,' 1987, Report of the Study Commission on Intensive Livestock Farming, established by the Dutch Society for the Protection of Animals.

27 *Ibid.*.

28 Council Directive 86/113/EEC was, however, later annulled on procedural grounds. Unauthorized changes had been made by the General Secretariat in the preamble of the directive. The annulment was the result of a protest by the United Kingdom against these

changes. The stipulations of the directive as such, however, were not challenged and the measures were re-adopted as Council Directive 88/166/EEC. (Eurogroup for Animal Welfare, Summary of Legislation relative to Animal Welfare at the levels of the European Economic Community and the Council of Europe, revised September 1989).

29 In the Netherlands, these requirements have indeed applied as of January, 1995. In late 1994, however, a larger number of farmers had not yet modified their cage systems (*Volkskrant*, 19 December 1994).

30 Eurogroup for Animal Welfare, Summary of Legislation relative to Animal Welfare at the levels of the European Community and the Council of Europe, revised September 1989; *Poultry*, April/May 1989, 33-34.

31 *Poultry*, April/May 1989, 33-34; *World Poultry* 7(1991)5, 32-35. In Southern Europe and the USA there are no or less stringent legal requirements. In the USA for example a floor area of 315 cm^2 per chicken is usual (R. Wegner, 'Poultry Welfare - problems and research to solve them,' *World's Poultry Science Journal*, 46(1990)1, 19-30).

32 Wegner, *Op. cit.*; Kuit *et al.*, *Op. cit.*; H.J. Blokhuis and J.H.M. Metz (1992), 'Tussentijdse evaluatie van het programma "Ontwikkeling en praktijkbeproeving van volière-huisvestingssystemen voor leghennen",' Nota P-92-59 van COVP-DLO en IMAG-DLO. In some countries like the Netherlands applied research had already commenced some years earlier

33 Wegner, *Op. cit.*, 20.

34 Blokhuis & Metz, *Op. cit.*, 5.

35 Currently the laying poultry farmers are willing to pay for a project at the Spelderholt to adapt the battery cage to chicken welfare requirements. This time, they want to keep the project beyond government interference.

36 An initiative law is a law proposed by parliament, instead of by the government.

37 *Pluimveehouderij,* 31 August 1990, 10-11.

38 *Oogst*, 9 November 1990, 60-63.

39 *Pluimveehouderij*, 30 June 1989, 6, my translation.

40 *Pluimveehouderij*, 30 June 1989, 6, my translation.

41 *Publications Pluimveehouderij 1990,* 4-7.

42 *Publications Pluimveehouderij 1990*, 4, my translation.

43 *Agrarisch Dagblad*, 8 November 1990, my translation.

44 *Pluimveehouderij,* 30 June 1989, 5.

45 *Publications Pluimveehouderij 1990*, 16-17; *Pluimveehouderij* 22 May, 1992, 8-10; *Pluimveehouderij,* 12 July, 1991, 8-9.

46 *Pluimveehouderij,* 21 February, 1992, 10-11.

47 *Cf.* Harrison, *Op. cit. 1993.*

48 Ketelaars, *Op. cit.*.

49 'Runs' on banks and stock-exchange panics are good examples (and also classic illustrations of the 'irrational' unintended effects of 'rational' actions by individuals).

50 At the moment, they finance research at the *Spelderholt* on adapted battery cages with welfare-augmenting elements.

51 Growing antagonism between poultry farmers and the government with respect to the aviary also brought the *Spelderholt* in a difficult position. It defended itself vis-à-vis the poultry farmers by saying that it only carried out research; it was up to the government to take political decisions about a possible ban on the battery cage.

52 Scharrelkrant Dierenbescherming, my translation.

53 For the notion of protected space, see Van Lente (1993). See also Rip (1992), Schot (1992) and the discussion in Chapter 8.

54 H.G. Mos, 'De inrichting voor het zuiveren van rioolwater te Enschede,' *De Ingenieur*, 38(1923)23, 447-449. Quotations below are from this article.

55 See e.g. *Ingenieur*: 18(1913)36, 736-761; 39(1924)16, 285-295 and 42(1927)20, 430-445.

56 For more details and references, see Appendix 3.

57 Cf. A.F. Rozich & F.G. Gaudt, *Design and Operation of Activated Sludge Processes Using Resiprometry* (Boca Raton etc.: Lewis Publishers, 1992), 1.

58 Alongside with microbiological disciplines, chemical disciplines acquired a larger role in sewage treatment plant design. Both transformations came together when a biotechnological approach came to be pleaded for. Biotechnology combines chemical and (micro)biological insights. Especially in the first parts of this story, however, I will focus on the role of microbiological disciplines.

59 This process of transformation was initiated by such groups as environmentalists and biologists. Eventually, it would result in a *demand* upon biologists and ecologists with respect to water quality assessment.

60 This section is based J.H. Riemersma, 'Reiniging van Afvalwater' (Overgedrukt uit Vragen des Tijds, 26 pp.) (1902); J. Smit, *De Hedendaagsche Stand van het Vraagstuk der Zuivering van Huishoudelijk en Industriëel afvalwater* (Rotterdam: Nijgh & Van Ditmar's Uitgeverij-Maatschappij, 1925); A.M. Buswell, *The Chemistry of Water and Sewage Treatment* (New York: The Chemical Catalog Company, 1928), American Chemical Society Monograph Series; P. Nauta, *Zuivering van afvalwater; Methoden en installaties voor de zuivering van Rioolwater en Industrieel Afvalwater* (met een inleiding van Prof.dr. Jan Smit) (Amsterdam: Ahrend & Zoon, 1937); P.L. Gainey & Th.L. Lord, *Microbiology of Water and Sewage* (Second printing 1956) (London: Longmans, Green & Co, 1952), 315-378; R.E. McKinney, *Microbiology for Sanitary Engineers* (New York etc.: McGraw Hill, 1962); H.A. Hawkes, *The Ecology of Waster Water Treatment* (Oxford etc.: Pergamon Press, 1963); P.G. Fohr, *Van Wilde bevloeiing tot moderne afvalwaterzuivering* (Wageningen: Veenman & Zonen, 1966), Rede uitgesproken bij de aanvaarding van het ambt van buitengewoon hoogleraar in de waterzuivering aan de Landbouwhogeschool te Wageningen op 23 juni 1966; Rijksinstituut voor de Zuivering van Afvalwater, *50 jaar zuivering van afvalwater* (bevat bijdragen van diverse auteurs) (Den Haag: Staatsuitgeverij, 1970); H. van Zon, *Een zeer onfrisse geschiedenis; Studies over niet-industriële vervuiling in Nederland, 1850-1920* (Groningen: Rijksuniversiteit Groningen, 1986), proefschrift; N.F. Gray, *Biology of Wastewater Treatment* (Oxford etc.: Oxford University Press, 1989); Centrale Archief Selectiedienst Ministerie van Binnenlandse Zaken, *Inventaris van de archieven van het Rijksinstituut voor Zuivering van Afvalwater (RIZA) en de daarop toezichthoudende commissies (1905-) 1920- 1975 (-1980)* (Winschoten: Centrale Archief Selectiedienst, 1990); N. Groeneveld, *Afvalwaterzuiveringstechnieken* (mmv Dr. E. Nijhof, Ir. J. van Selm, Ing. S.A. Oldenkamp) (Zeist: Stichting Projectenbureau Industrieel Erfgoed, 1994), PIE Rapportenreeks 10; S. Beder, 'Pipelines and Paradigms: The Development of Sewerage Engineering', *Australian Civil Engineering Transactions*, CE35(1993)1 (1993), 79-85; *De Ingenieur*: 42(1927)20, 430-445; 50(1965)46, G37-G38; 50(1935)46, G38-G40; 50(1935)46, G47-G49; 50(1935)12; 51(1936)11, G1-G6; 59(1947)35, G59-G65; 62(1950)4, G11-G12; 65(1952)12, G9-G13; 71(1959)31; 72(1960)27, A371-A377; 73(1961)32, G41-G50; 76(1964)31, A451-A456; *H2O*: 3(1970)21, 511-520, 5(1972)13, 268-273; 6(1973)19, 491-496; 8(1975)1, 2-5; 13(1980)22, 525; 21(1988)11, 288-291; 22(1989)13, 398-399; 26(1993)6, 142-147; *Land + Water:* Juni 1959, 100-105; Augustus 1959, 144-153, 4(1960)5, 220-228; *Cultuurtechniek*: 1(1963)2, 52-55; *Water*: 48(1964)7, 90-91; 48(1964)21, 288-290; 51(1967)5, 463-464.

61 *Cf.* Rijksinstituut voor de Zuivering van Afvalwater, *Op. cit.*; *De Ingenieur*, 50(1935)46, G47-G49.

62On the RIZA see: Centrale Archief Selectiedienst Ministerie van Binnenlandse Zaken, *Op. cit.* ; Rijksinstituut voor de Zuivering van Afvalwater, *Op. cit*; Groeneveld, *Op. cit.*, 15-16 and H_2O, 9(1976)23, 479-483.

63 P.G. Fohr, *Van wilde bevloeiing tot moderne afvalwaterzuivering* (Wageningen: Veenman & Zonen, 1966), Rede uitgesproken bij de aanvaarding van het ambt van buitengewoon hoogleraar in de waterzuivering aan de Landbouwhogeschool te Wageningen op 23 juni 1966; Rijksinstituut voor de Zuivering van Afvalwater, *Op. cit.*.

64 Sanitary engineering is a somewhat broad field that includes such diversified topics as sewage treatment, (drinking) water supply, soil pollution, the sanitation of houses, institutions and recreational places and heating & ventilation.
Sanitary engineering was usually taught as a part of civil engineering. In the USA, sanitary engineering has become more or less a distinct profession in the twentieth century. In the rest of the world, sanitary engineering did not develop as a distinct discipline as early as in the USA. In Europe engineers were involved in what can be called 'sanitary engineering works,' but they had mostly received no special training in this area. In the Netherlands, these people often had a chemical or agricultural engineering background.

65 For sanitary engineering education between the thirties and seventies in the Netherlands see *De Ingenieur* 50(1935)12, A108-A109; 50(1935)46, G37-G38; 50(1935)46, G38-G40; 59(1947)35, G59-G65; 62(1950)4, G11-G12; 65(1952)12, G9-G13; 71(1959)31, G65-G74; 72(1960)27, A371-A377; 73(1961)32, G41-G50; 76(1964)31, A451-A456; 77(1965)35, A533-A536; 91(1979)19, 339-340; *Jubileumuitgave de Ingenieur*, (1947), 153; and H_2O: 8(1975)1, 2-5; 10(1977)24, 541-545 and 551; 11(1978)11, 226-229; 13(1980)8, 161-165; 7(1984)20, 452-456.
Between 1937 and 1952, a course in sanitary engineering was organized by the KIVI. The course attracted about 100 participants yearly. The course consisted of eight afternoons or evenings; each year a different topic was treated. The courses ended when professor Burger was appointed in 1952 to give courses in Technical Hygiene at the Technical College Delft. In 1959, a number of postgraduate courses in Sanitary Engineering started. These courses were organized by the KIVI and the Technical College Delft. The course consisted of three sub-courses: in Civil Sanitary Engineering, in Industrial Sanitary Engineering and in Constructional Sanitary Engineering. As in the case of 'regular' civil sanitary engineering courses at Delft, most of the courses in the Postgraduate Course Civil Sanitary Engineering were related to water (sewage treatment, drinking water supply). Some chemical and biological topics were treated too . The Postgraduate Course in Civil Sanitary Engineering was given in thirty days spread over the year. Until 1965, 191 people followed the Postgraduate Course in Civil Sanitary Engineering. In 1966, also summer courses in waste water treatment started at the Technical College Delft.

66 Civil sanitary engineering became one of the seven main subjects, which students in civil engineering could chose.

67 McKinney, *Op. cit.*, vii.

68 Mc Kinney, *Op. cit.*, vii.

69 Hawkes, *Op. cit. 1963*, vii.

70 J. Kuiper, 'De rol van protozoën in de waterzuivering,' H_2O, 6(1973)19, 491-496.

71 Hawkes, *Op. cit. 1963*, vii.

72 D.A. Okun, 'Sanitary Engineering Education in a Changing World,' *De Ingenieur*, 73(1961)32, G41-G50. Quote from page G46.

73 *Ibid.*

74 McKinney, *Op. cit.*, vii. The second clearly was the purpose of McKinney's book, which 'was designed to teach future sanitary engineering at M.I.T..' (*Ibid.*)

75 McKinney, *Op. cit.*, vii.

76 McKinney, *Op. cit.*, 233.

77 *Cf.* Buswell, *Op. cit.*, 331-353.

78 McKinney, *Op. cit.*, vii. Indeed, Dutch sanitary engineers and chemists have accused biologists of being interested only in taxonomies and pure cultures until recently (Interview Fohr, 19 June 1995; Interview Van der Graaf, 8 December 1995; Interview Dirkzwager, 31 August 1994).

79 McKinney, *Op. cit.*, 5.

80 This 'problematic' relationship was not only typical of (micro)biology. Of the other (sub)disciplines like biochemistry, colloid chemistry and organic chemistry that, in principle, might be relevant for understanding sewage treatment processes, at least the relationship between organic chemistry and sanitary engineering was problematic. As a 1967 textbook on

chemistry for sanitary engineers explains, the interests of organic chemistry and sanitary engineering did not necessarily harmonize: 'The fundamental information that a sanitary engineer needs concerning organic chemistry differs considerably from that which the chemist requires. This difference is due to the fact chemists are concerned principally with the synthesis of compounds, whereas the sanitary engineer is concerned, in the main, with how organic compounds in liquid, solid and gaseous wastes can be destroyed.' (C.N. Sawyer & P.L. McCarty, *Chemistry for Sanitary Engineers* (Second Edition 1968) (New York etc.: Mc Graw-Hill, 1967), McGraw-Hill Series in Sanitary Science and Water Resources Engineering, 86) They go on to point out that: 'Another major difference lies in the fact that the organic chemist is usually concerned with the product of the reaction; the by-products of a reaction are of little interest to him.'(*Ibid.)* The sanitary engineer, however, mostly wants to reduce the production of 'by-products' or to ensure at least that they are not harmful, but '[u]nfortunately organic chemists have presented little information on the nature of the by-products of reactions' (*Ibid.*, 87).

81 C.R. Curds & H.A. Hawkes (eds.), *Ecological Aspects of Used-water Treatment* (Vol. 2) (London etc.: Academic Press, 1983), vii. See also interview Fohr, 19 June 1995; Interview Van der Graaf, 8 December 1994.

82 For the 'Smeerpijp' affair see *De Ingenieur*: 82(1970)5, A67-A73; 82(1970)36, A685-A696, and 83(1971)24, A406-A413; *H_2O*: 3(1970)19, 47; 3(1970)23, 620-621; 3(1970)26, 708-711; 4(1971)3, 66-67; 4(1971)4, 90-91; 4(1971)6, 134-135; 5(1972)3, 56; 5(1972)4, 81-82; 6(1973)1, 25; 6(1973)20, 531; (1976), N 98; 10(1977)19, 456; 13(1980)3; and 16(1983)19, 425-432; J. Lok & J. Schreuder, *Veenkoloniaal Afvalwater: Nu zuiveren of nooit* (Uitgave van Werkgroep Eemsmond, Milieufederatie Groningen en Landelijke Vereniging tot Behoud van de Waddenzee) (Harlingen: 'Het Waddenhuis,' 1979), 1-4; P. de Wolf, H. Veldkamp & C. van den Hoek, 'Voordrachten, gehouden tijdens de informatiedag Biologisch Onderzoek Veenkoloniaal Afvalwater 12 december 1975,' Biologisch Onderzoek Veenkoloniaal Afvalwater Eems Dollard Project Publikaties en Verslagen nummer 1 - 1976, 1-2. See also Van Zon, *Op. cit.*.

83 A.C.J. Koot, 'De dimensionering van rioolwaterzuiveringsinrichtingen,' *Water*, 51(1967)9, 185-192. Among the same time, several other articles appeared in the journal *Water* on the dimensioning and design fundamentals of sewage treatment plants; most of these articles were (partly) based on earlier foreign research. See H.J. Eggink, 'Oxydatiesloten; Grondslagen en ervaringen,' *Water*, 48(1964)25, 343-346; A. Pasveer, 'Oxydatiesloten; Grondslagen en ervaringen,' *Water*, 48(1964)21, 285-287; A. Pasveer, 'Oxydatiesloten; Grondslagen en ervaringen,' *Water*, 49(1965)14, 211-214; C.J.C. Smeets, 'Berekeningsgrondslagen voor actief-slibinstallaties,' *Water*, 50(1966)16, 243-253; H. Peters, 'Berekeningsgrondslagen voor actief-slibinstallaties,' *Water*, 50(1966)26, 423-424; C.J.C. Smeets, 'Repliek,' *Water*, 50(1966)26, 424-425.

84 A.C.J. Koot, *Behandeling van Afvalwater* (Delft: Waltman, 1974).

85 Box 5.3 is mainly based on N.F. Gray, *Activated Sludge, Theory and Practice* (Oxford etc.: Oxford University Press, 1990).

86 See the literature cited in note 60.

87 See *De Ingenieur*, 69(1957)17; *H_2O*: 3(1970)22, 551-560; 7(1974)23, 521-523; 16(1983)19, 425-432 and 17(1984)19, 426-430; A. Pasveer, *Eenvoudige Afvalwaterzuivering* (rapport no. 26) (Den Haag: Instituut voor Gezondheidstechniek TNO, 1958); *DHV Water Nieuws*, Special 25 jaar Carrousel; Interview Schutte, 7 August 1995.

88 The design fundamentals with respect to the aerators (and aeration regime), sludge return and removal as they play a role in the activated sludge plant design are not discussed here. The parameters and rules of thumbs, which Koot formulates, are to a large extent compatible with those presented in other studies. For example Hawkes' description of the activated sludge process (and the relevant parameters) resembles Koot's description in remarkable detail (H.A. Hawkes, 'Activated Sludge,' in C.R. Curds & H.A. Hawkes (eds.), *Ecological aspects of Used-water treatment, Volume 2 Biological Activities and Treatment Processes* (London etc.: Academic Press, 1983), 77-162).

89 Koot, *Op. cit. 1967*, 187, my translation. See also Koot, *Op. cit. 1974*, 165 and *Water*, 48(1964)9, 120-124.

90 Before the use of parameters like sludge load, activated sludge plants were often dimensioned on the basis of the flow of waste water and a particular retention period (which was based on experience). Nauta (*Op. cit.*, 139-140) in his 1937 book gives the following example. The flow of waste water is given to be 417 [m^3/u] and the retention time is set on 6 [u]. Hence the required volume of the aeration tank is 6 * 417 = 2502 [m^3]. Clearly in this example, biological insights play no role whatsoever.

91H.A. Hawkes, 'The Applied Significance of Ecological Studies of Aerobic Processes,' in C.R. Curds & H.A. Hawkes (eds.), *Ecological Aspects of Used-water treatment, Vol. 3 The Processes and their Ecology* (London etc.: Academic Press, 1983), 174ff.

92 *Ibid.*. See also McKinney, *Op. cit.*.

93 The parameters function like what Susan Leigh Star has called a *boundary object*: 'objects which are both plastic enough to adapt to local needs and the constraints of several parties emplacing them, yet robust enough to maintain a common identity across sites' (Star & Griesemer, 1989, 393).

94 This does not mean that design parameters for sewage treatment plans can be applied in a straightforward way. For many aspects of sewage treatment plant design, parameters do not provide a solution. One such a problem is that quality (BOD) and quantity of the waste water to be purified in a sewage treatment plant may change from hour to hour and day to day. This has consequences for the purifying capacity of the bacteria in the plant that cannot be foreseen with the help of parameters. A related problem is that the composition of waste water will change from location to location. For such reasons, it is often necessary to do large-scale experiments or to provide the plant with a large buffer capacity. It is also for such reasons that many designers of sewage treatment plants maintain that designing a sewage treatment plant has little do with the 'mechanical' application of particular parameters, but in the first place requires *feeling* for the kinetics and dynamics of the treatment process.

95 Interview Van der Graaf, 8-12-1994; Interview Witvoet, 10-2-1995; Interview Fohr, 19-6-1995; Interview Schutte, 7-8-1995. That it were engineering firms and Water Boards were these people were employed is due to the fact that the interval between the early fifties and early seventies witnessed shifts in the division of design labor within the technological regime of sewage treatment plants. Between 1947 and about 1975, Water Boards took over the responsibility for sewage treatment from municipalities. In the meantime the prominent position of the RIZA in the design of sewage treatment plants was taken over by engineering firms. For more details, see Appendix 3.

96 *Water* 46(1962), 338.

97 *Ibid.*.

98 See RIZA, *Op. cit.*; Groeneveld, *Op. cit.*; Van Zon, *Op. cit.*; *H_2O*: 3(1970)26, 712-713; 5(1972)13, 268-273; 5(1972)21, 492-497; 7(1974)16, 322-324; 9(1976)23 (1976), 479-483; 16(1983)19 (1983), 425-432; 17(1984)19 (1984), 426-430; 17(1984)19, 421-425; A.H. Dirkzwager, E. Eggers & M.M.A. Ferdinandy-van Vlerken, 'Developments in waste water technologies and municipal waste water treatment systems in the future', *European Water Pollution Control*, 4(1994)1, 9-19.

99 Ministerie van Verkeer en Waterstaat, *De bestrijding van de verontreiniging van het oppervlaktewater; Indicatief meerjarenprogramma 1975-1979* (Den Haag: Staatsuitgeverij, 1975).

100 This figure is based on W.A.H. Brouwer, 'Stand van de Rioolwaterzuivering in Nederland,' *Water*, 46(1962)10 (1962), 155-157; A.H. Dirkzwager, E. Eggers & M.M.A. Ferdinandy-van Vlerken, 'Developments in waste water technologies and municipal waste water treatment systems in the future,' *European Water Pollution Control*, 4(1994)1 (1994), 9-19; A.H. Dirkzwager, 'Water Management and Waste Water Treatment in the Netherlands' (1992), paper Aquatech, Amsterdam, 3 September 1992; Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer & Ministerie van Landbouw en Visserij, *Derde Nota Waterhuishouding* (Den Haag: SDU, 1989), 100; Ministerie van Verkeer en Waterstaat, *De bestrijding van de verontreiniging van het oppervlaktewater; Indicatief meerjarenprogramma 1975-1979* (Den Haag: Staatsuitgeverij, 1975), 16 and on data from the CBS.

101 Until the mid-sixties, trickling filters were the dominant biological treatment method. Compared with the activated sludge system, trickling filters were easier to build (less moving parts) and to operate. Moreover, they were more robust, produced less excess sludge and consumed less energy. Trickling filter had, however, also a number of disadvantages: the BOD-removal of trickling filters was lower than that of activated sludge plants, the method was more vulnerable to temperature drops which implied that it did often not function properly during winter, the filter attracted flies and the purification process could not be controlled as closely as in the case of activated sludge plants. Moreover, the enhanced training of operators and, later, the growing possibilities of automated process control made traditional advantages of the trickling filter like robustness and ease of operation less important. Hence, in the seventies activated sludge plants - in many cases Pasveer Ditches, Carrousels and other low rated activated sludge variants of the conventional aeration tank - became the standard design. (see Gray, *Op. cit. 1990*, 6; Gainey & Lord, *Op. cit.*; Groenewegen, *Op. cit.*; H_2O, 16(1983)19, 425-432).

102 On the development of (dynamic) models and their use in the design process see S.E. Jorgensen & M.J. Gromiec (eds.), *Mathematical Models in Biological Waste Water Treatment* (Amsterdam etc.: Elsevier, 1985); C.P.L. Grady, 'Dynamic Modeling of Suspended Growth Biological Wastewater Treatment Processes (Chapter 1),' in G.P. Gilles & D. Chapman (eds.), *Dynamic modelling and expert systems in wastewater engineering* (Chelsea (Michigan): Lewis, 1989), 1-38; Gray, *Op. cit. 1990*; T.M. Keinath & M.P. Wanielista (eds.), *Mathematical Modelling for Water Pollution Control Processes* (Ann Arbor: Ann Arbor Science, 1975); A.F. Rozich & F.G. Gaudt, *Op. cit.*; H_2O, 28(1995)9, 281-283; Interview Dirkzwager, 31 August 1994; Interview Reitsma, 2 December 1994; Interview Rensink 10 January 1995; Interview Van der Graaf 8 December 1994; Interview Witvoet, 10 February 1995; Interview Kruit, 19 September 1995.

103 This warning seems to reveal the same kind of tension that exist with respect to the use of parameters. On the one hand, parameters and models may be helpful in design and offer some insight in the relevant processes; on the other hand they necessarily blackbox these processes and may 'replace' insight. Hence, in principle, the advance and use of parameters and models may increase as well as diminish the awareness of and the insight in the complex nature of the purification process. In practice, the developed (dynamic) models seem to have became a design tool in addition to, instead of replacing existing design tools like design fundamentals, parameters, rules of thumb, experience and (full-scale) experiments. It may sound paradoxical, but the skeptical reaction of (some) designers to the developed models is the best proof that these models have not yet decreased the awareness of the complex nature of the purification process.

104 *Water*, 50(1966)23, 371, my translation.

105 *Ibid.*, 372, my translation.

106 *Cf.* A. Rip & W. van der Es, 'Biotechnologie: ontwikkeling en sturende impulsen,' in A. Rip & P. Groenewegen (eds.), *Macht over Kennis; mogelijkheden van wetenschapsbeleid* (Alphen aan den Rijn/Brussel: Samson, 1980), 248-263 and Gray, *Op. cit. 1989*, 655.

107 The description of biotechnology as a generic field is based on Rip & Van der Es, *Op. cit.*.

108 The description below of biotechnological research at Delft in relation to sewage treatment is based on Anonymus, 'Biotechnologen duiken in afvalwaterzuivering,' *Milieutechniek*, (1988)10, 137-138 and Interview Kuenen, 15 September 1995.

109 Researchers from Delft, Wageningen and Leiden are cooperating in the school *Biotechnological Sciences Delft Leiden.* Two departments from Wageningen are part of this research school. The department in Wageningen that has been traditionally involved in waste water treatment research - the Department of Water Treatment (now: Environmental Technology) - is, however, not a part of this research school.

110 This box is based on H_2O: 14(1981)13, 297-299; 14(1981)24, 568-570; 16(1983)12, 266-269; 17(1984)4, 78-81; 17(1984)5, 94-100; 17(1984)19, 426-430; 19(1986)23, 557-561; 20(1987)16, 375-380; 20(1987)25, 640-644; 21(1988)5, 111-115; 21(1988)15 (1988), 426-428; 24(1991)2, 42-44; 27(1994)2, 41-48; *Milieu Markt*, January/February 1994, 16-17; December 1993; *Land + Water*, June 1993, 70-71; *Milieu Magazine*, (1993)4, 4-7; *Chemisch Magazine*, September 1993, 368-371; *ROM* (1993)6, 38-46; E. Vermeij, *Contextuele verschillen in de*

ontwikkeling van technische toepassingen van Methaangisting (TWIM-Studies, nummer 9) (Eindhoven: TWIM, 1990), Doctoraalscriptie.

111 G. Lettinga, *Zuiver denken en ecologisch zuiveren* (Wageningen: Landbouwuniversiteit, 1989), Inaugurale rede.

112 J.J. Heijnen & M.C.M. van Loosdrecht, 'Biofilm kan hoofdrol spelen in aerobe afvalwaterzuivering,' *I^2 Procestechnologie*, (1990)1, 29-33. Before he came professor in Delft, Heijnen had been working at the Dutch biotechnological firm Gist-Brocades, where he had played an important role in the development of a new reactor concept for waste water treatment.

113 J.H.J.M. van der Graaf, *Afvalwater, zuiver en klaar?* (Delft: Technische Universiteit Delft, 1990), Inaugurale rede.

114 For the development of more stringent effluent standards see especially Dirkzwager *et al.*, *Op. cit.*; A.H. Dirkzwager, 'Water Management and Waste Water Treatment in the Netherlands,' paper Aquatech, Amsterdam, 3 September 1992.

115 Phosphate and nitrogen contribute to so-called eutrophication, leading to a vast growth of algae in the water. When these algae die, the oxygen concentration in the water drops significantly, resulting in stench and dead fish. This environmental problem was already attracting a lot of attention in the seventies. Eutrophication is not only abated by treatment measures, but also by partially successful attempts to reduce the discharge of phosphates. In detergents, for example, phosphates have been replaced, mainly as a result of public pressure. At the moment, agriculture is the largest source of phosphate in the surface water.

116 For more details, see Appendix 3.

117 *H_2O*: 7(1974)19, 396-197, 10(1977)24, 541-545 and 551; 11(1978)11, 226-229, 13(1980)8, 161-165, 7(1984)20, 452-456 and 18(1985)16, 340-342.

118 *ROM*, 1993(9), 38. Initially, it was established by seven Water Boards. Later, all other Water Boards and the RIZA have begun to participate in the STORA. In 1992 STORA was transformed in Foundation for Applied Waste Management Research or STOWA (*Stichting Toegepast Onderzoek Waterbeheer*).

119 Interview Kruit, 15 September 1995. See also Interview Rensink, 10 January 1995.

120 *Ibid.*.

121 *H_2O*: (1976)15, 279-283; 26(1993)22, 639-641 and(1994)11, 310-313; Interview Reitsma, 2 December 1995; Interview Kruit, 19 September 1995. Dynamic models must first be calibrated in order to be useful in practical circumstances: the parameters in the model must fit the local circumstances.

122 Interview Kruit, 19 September 1995.

123For N-removal see *H_2O*: 7(1974)15, 303-311; 7(1974)22, 489-496; 10(1977)9, 208-209; 23(1990)11, 300-303 and 307; Dirkzwager *et al.*, *op. cit.*; Gray, *Op. cit. 1990*, 153-167; P.J. Roeleveld, E.H. Marsman, B.A.H. Reitsma, *et al.*, 'A three sludge sewage treatment plant (pilot plant results),' Wageningen Agricultural University and TAUW Milieu, Leaflet; *DHV Times*, September 1994; Interview Kuenen, 15 September 1995.

124 Biotechnological researchers from Delft, for example, played a major role in the development of a special additive nitrogen removal stage for the sewage treatment plant *Dokhaven* in Rotterdam. See *Delft Outlook*, (1995)2, 14-17.

125 If sanitary engineers were interested in a contribution from biologists or chemists, they complained about the fact that those professionals were scarcely interested in the field (Interview Dirkzwager, 31 August 1994).

126 The description of P-removal below is based on *H_2O*, 9(1976)5, 88-93; 16(1983)12, 285-287; 21(1988)2, 43-45; 21(1988)9, 243-245 and 22(1989)4, 122-123; Gray, *Op. cit. 1990*, 167-175; Dirkzwager *et al.*, *Op. cit.*; W. van Starkenburg & K. Visscher, 'Biologisch defosfateren: een toekomst perspectief,' *H_2O*, 601-602+606; Witteveen + Bos, Dienst Binnenwateren/RIZA, 'Knelpunten bij de invoering van defosfatering' (December 1988), STORA Report, Werk no. Lls.65.1 BS/38; *DHV Times*, September 1994; Interview Dirkzwager, 31 August 1994; Interview Rensink, 10 January 1995; Interview Kruit, 19 September 1995.

127 One of the biological phosphate removal processes requires the use of chemicals to remove the phosphate from the return sludge of an activated sludge plant. The amount of chemicals needed is, however, lower than in the case chemical treatment.

128 Until recently, biochemical methods to remove phosphate were scarcely practiced in the Netherlands. In 1990, 35 Dutch sewage treatment plants were employing phosphate removal, none of them by biological means.

129 Interview Kruit, 19 September 1995.

130 *Cf. Milieutechniek*, (1988)10, 137-138; Beder, *Op. cit;* Interview Kruit, 19 September 1996; Interview Kuenen, 15 september 1995. The newest Dutch installations like the recently built *Dokhaven* plant surely have innovative characteristics, but essentially they are based on the activated sludge process and staged treatment of sewage.

131 Interview Kruit, 19 September 1995. *Cf.* also literature cited in note 110.

132 On these long-term problems (and options) see: *H_2O*: 13(1980)14, 313-317; 16(1983)19, 425-432; 17(1984)5, 94-100; 17(1984)19, 426-430; 20(1987)6, 124-125; 21(1988)5, 111-115; 22(1989)5, 138-140; 22(1989)22, 684-688; 26(1993)3, 77-80 and 26(1993)5, 135; *Milieu Markt*, January/February 1994, 23-25.; *ROM*, (1993)9, 38-46; *Milieutechniek*, (1988)10, 137-138; *Land + Water nu*, (1989)11, 103-104; Dirkzwager *et al.*, *Op. cit.*; Interview Kruit, 19 September 1995; Interview Reitsma, 12 December 1994; Interview Rensink, 10 January 1995.

133 *Milieutechniek*, (1988)10, 137-138; *Land + Water nu*, (1989)11, 103-104; *H_2O*, 22(1989)22, 684-688; *ROM* (1993)6, 38-46.

134 At the moment, also the central government is funding research in environmental biotechnology, although the attempts are still bleak compared with the governmental funding of industrial biotechnology by the Dutch government in the eighties (Interview Kuenen, 15 September 1995).

135 This resistance of (professional) users like poultry farmers against innovations is not typical for regimes with a user-driven innovation pattern. We saw a comparable phenomenon in the preceding chapter in the case of painters and other professional users of paints. In both cases, the resistance of professional users did not solely or merely derive from their conservatism or attitudes but also from their economic position in relation to the (expected) tradeoffs of technological alternatives. In both cases, professional users depended on their users for the acceptance of particular innovations. Beforehand, they did - and do - not know whether their users would buy alternatives products, but most of them did not want to take the economic risk, because if they failed they would lose ground to their competitors and might eventually go bankrupt.

6

Mouths More Difficult to Close Than the Oosterschelde

Coastal Barriers and Waterside Banks

In 1967, the Zeeland Council of the Sciences organized a congress about the closure of the *Oosterschelde*. After a huge storm flood in 1953, it had been decided to close off this ecologically unique estuary in the south-west of the Netherlands as part of the so-called Delta Plan. When the date of closure was approaching, ever more people became critical about the planned closure. For these people, the congress of the Zeeland Council of Sciences was one of the first opportunities to raise their voices. Although most opponents of closure at that moment believed that the *Oosterschelde* would be closed, some of them were determined to keep on raising their voice. One of them expressed it as follows at the end of the meeting:

> *Many people who like this beautiful, in many respects unique area, will raise their voices again; after all their mouths are still more difficult to close than that of the Oosterschelde.*[1]

In the event, the protests against the closure of the *Oosterschelde* were successful. In the seventies, the Dutch government decided to build a storm surge barrier in the *Oosterschelde*. (A storm surge barrier is a semipermeable barrier that can be closed in case of a storm flood.)

The decision to build a storm surge barrier resulted in a demand upon ecologists and biologists. Eventually, this cumulated in the articulation of a new multifunctional approach to the design of hydraulic works. This approach has become known as integrated water management. In integrated water management, the water system is taken as point of departure for design and management decisions. This means that the different functions of water systems - like safety, water regulation, shipping, ecology and recreation - should be taken into account during the design of hydraulic works like coastal barriers. The partial acceptance of integrated water management as new guiding principle implies that ecological criteria have become more important in the regime of coastal barriers.

The regime of coastal barriers was, and is, characterized by a mission-oriented innovation pattern. The governmental agency Rijkswaterstaat formulates missions for specific coastal projects. These missions have to be approved by the central government. Innovations in the regime of coastal barriers are usually achieved in relation to specific coastal projects. Rijkswaterstaat acts as principal for those projects, often carries out most of the design tasks and carries out and commissions research on coastal barriers. The contributions of other actors to the design and research on coastal barriers are to an important extent controlled by Rijkswaterstaat. So, Rijkswaterstaat can formulate missions for specific coastal projects and the regime as a whole. Therefore, Rijkswaterstaat will usually be the initiator of innovations in the regime of coastal barriers.

This existing innovation pattern enabled and constrained the studied process of transformation. It enabled the process of transformation because the ‘mission actors’ - Rijkswaterstaat and the central government - are subject to political and democratic decision-making. This made it possible to urge for a reformulation of the mission of the *Oosterschelde* project via the mobilization of public opinion and democratic decision-making. The mission-oriented innovation pattern was further enabling because, once a new mission was formulated, it could rather effectively be implemented. This is due to the important role that the government agency Rijkswaterstaat plays in the regime. This is not to suggest that Rijkswaterstaat or the central government could simply enforce a new mission, but they are in a relatively good position to do so, compared with technological regimes with another innovation pattern.

The important, if not dominant, position of Rijkswaterstaat in the existing regime also constrained the process of transformation. To some extent, Rijkswaterstaat could block the reformulation of the mission of the *Oosterschelde* project. Rijkswaterstaat possessed crucial technological knowledge to assess which kinds of missions would be technologically feasible. Moreover, Rijkswaterstaat had some control over R&D with respect to coastal barriers and over the development and acceptance of specific technical alternatives.

The second case that I study in this chapter is waterside bank protections. This technological regime is also characterized by a mission-oriented innovation pattern. The process of transformation I study is related to the striving for ecologically sound banks. This process of transformation is similar to that in the regime of coastal barriers in several respects. Both processes of transformation started out in response to the manifestation of the aggression of the current regime toward the environment. In both cases, this resulted in ecological design criteria becoming more important over time and in a demand upon ecologists and biologists. Eventually, in both cases a new design approach was articulated that was in line with integrated water management.

All mentioned similarities between the two processes of transformation are contingent on the existing mission-oriented innovation pattern of both regimes. They are, however, not quite accidental. In fact, they are related to several general transformations that have taken place in water management during the last decades. These transformations can be summarized by saying that integrated water management has increasingly begun to function as a guiding principle in water management. Most actors involved legitimize their behavior with respect to water management (partly) by reference to the striving for integrated water management and, increasingly, their actions are guided by the striving for integrated water management. The implementation of integrated water management has, however, until now not been completely successful.

The mission-oriented innovation pattern enabled and constrained the process of transformation in the regime of waterside banks in a way that was similar to the first story. Transformation of the regime was achieved via a reformulation of the mission of the regime. In the waterside banks regime, however, the mission actors like Rijkswaterstaat could less effectively implement a new mission. This was the case because Rijkswaterstaat is less powerful in the regime of waterside banks than in the regime of coastal barriers.

6.1 Mouths More Difficult to Close Than the Oosterschelde[2]

In the last night of January 1953, the south-west of the Netherlands was attacked by a huge storm flood. Higher water levels than 'ever' were the result. Many dikes were destroyed. Large parts of the regions of *Zeeland* and *Zuid-Holland*, which are below sea-level, were flooded. 1835 people died; more than 72,000 people had to be evacuated. After the flood disaster a plan was conceived to protect the south-west of the Netherlands from this type of disasters: the Delta Plan.
Part of the Delta Plan was the design and construction of several coastal barriers. A technological regime of coastal barrier design then already existed in the Netherlands. This regime had mainly got shape with the closure of the *Zuiderzee* in the twenties. What had come about was a mission-oriented regime in which Rijkswaterstaat was the main actor.
In this case study, I describe the process of transformation that took shape after the formulation of the Delta Plan. This process of transformation was initiated by environmental groups, ecologists and biologists who, from the end of the sixties on, heavily criticized the closure of the *Oosterschelde* for its negative ecological consequences. The *Oosterschelde* was the largest and ecologically most valuable tidal inlet that would be closed off due to the Delta Plan. In the event, societal criticism resulted in the political decision to reformulate the mission of the *Oosterschelde* project and to build a semipermeable barrier in the *Oosterschelde*.

This story consists of four parts. The Sections 6.1.1 and 6.1.2 discuss the Delta Plan and the reformulation of the mission due to public protests in the seventies. In Section 6.1.3, I discuss how the reformulation of the mission of the *Oosterschelde* project resulted in a demand upon ecologists. The final section discusses the articulation of a new design approach and the degree to which this approach has been put in practice in the regime of coastal barriers.

6.1.1 The Delta Plan

The 1953 flood disaster came as a shock to the Netherlands. For the engineers of Rijkswaterstaat, however, the disaster came not completely unexpected. Hydraulic measurements in the Delta area and (model) research had already led to the conviction among a number of engineers from Rijkswaterstaat that the south-west of the Netherlands was insufficiently protected against the sea.[3] Around 1934, it was discovered that some dikes in the south-west of the Netherlands might be too low. Little publicity was given to this message.[4] Meanwhile, research went on and in 1939 the Storm Flood Committee (*Stormvloedcommissie*) was established. Especially one member of the *Stormvloedcommissie*, Van Veen, pleaded for drastic measures. Van Veen was an engineer working at the Study Department for Arms of the Sea, Rivers and Coasts (*Studiedienst voor de Zeearmen, Benedenrivieren en Kusten*) of Rijkswaterstaat. He had a hard time in convincing the *Stormvloedcommissie* of the necessity of measures. Van Veen's dogged conviction that drastic measures were to be taken, did not make him very popular. He was called 'the new Cassandra.'[5] It is said that he was forbidden to speak out in public.[6]

Already before the storm flood disaster of 1953, plans were conceived to protect the south-west of the Netherlands. Typically, until February 1953 the main (official) argument for damming up the tidal inlets was the creation of fresh water basins.[7] In 1948, a scale model of the Delta area came available, which made it possible to investigate the various plans for closure of tidal inlets. In 1950, the *Brielse Maas* was closed off. In December 1952, the Minister of Transport and Communications gave the order to study the closing off of the *Grevelingen* and the *Oosterschelde*, in addition to the plans that were already in study. The result was that two days before the storm flood disaster, Rijkswaterstaat (Van Veen) presented two new plans to the government.
It may sound cynical but the storm flood disaster was for the Rijkswaterstaat engineers, and especially Van Veen, not only a human tragedy but also an opportunity to realize the proposed closures of the tidal inlets. Van Veen himself - using the pseudonym Dr. Cassandra - later described his feelings immediately after the disaster as follows:

> *Many hundreds of miles of dikes had to be repaired. A single summer was a very short time . . . Anyhow, time would show quickly enough whether the nation and its engineers would be equal to their tasks. Heavy tasks as had not been taken up in the world before.*
> *He mused further. The great work of closing the Dutch coast, the plan for which he and his man had worked so hard during so many years, would surely start, now that the existing dikes had proved to be inadequate. The closing of these terrible storm-breaches would not be more than a mere beginning, just a prelude. The repair of the broken dikes would be undertaken so vigorously (he was sure about that), and successfully (he hoped), that the nation and its engineers might be inspired with necessary courage to commence the task of closing the whole Dutch coast, thus making it almost invulnerable for a long time to come.*[8]

Three weeks after the 1953 flood disaster, the Dutch government installed the Delta Committee to evaluate how a recurrence of the disaster could be prevented.[9] The committee consisted of twelve civil engineers, one economist and one agricultural engineer.[10]
The committee could choose two principal solutions: reinforcing the dikes in the area or shortening the coast line by closing off the main tidal inlets by barriers. Both options were comparable in estimated costs and timescale. Arguments for barriers were that they were easier to maintain and to strengthen, if necessary.[11] Moreover, damming up might help stop the erosion in especially the *Oosterschelde* and have advantageous secondary effects like fighting salinity (the disappearance of salt water from the sea would be beneficial for agriculture), improving fresh water supply and improving road connections.[12] The main disadvantage of closing off the tidal inlets was that is was technically more difficult and risky.

In the event, the Delta Committee proposed to close off all tidal inlets in the Delta Area, expect for two: the *Westerschelde* and the *Nieuwe Waterweg*, which are both important shipping routes (see Figure 6.1).[13] Apart from the sketched advantages, this decision was probably spurred by the fact that emotions ran high in the country and the overwhelming public opinion was: 'This never again.'

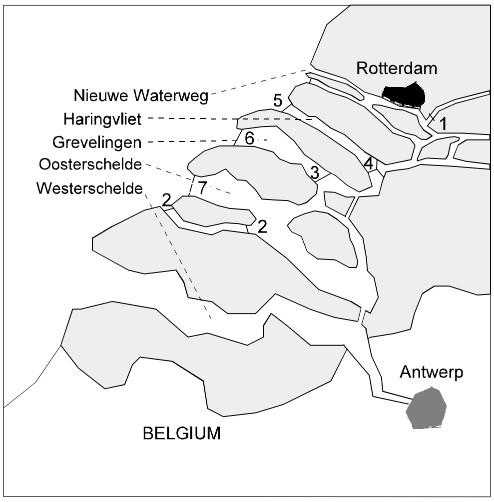


Figure 6.1 *The Delta Plan (in chronological order)*
1 Storm Surge Barrier *Hollandse Ijssel*
2 *Veerse Gat* and *Zandkreek* Barrier
3 *Grevelingen* Barrier
4 *Volkerak* Barrier
5 *Haringvliet* Barrier
6 *Brouwersdam*
7 *Oosterschelde* Barrier

Implied in the Delta plan were innovations, both in an organizational and in a technical sense. The Delta Plan required the management of a large project organization for design and construction. To design and build the Delta Works, a special Delta Department was established at Rijkswaterstaat.
Some Delta closures required technical solutions that were not yet available. This was especially true of the *Oosterschelde* closure, the largest tidal inlet to be closed. This closure was therefore scheduled for the final stages of the Delta Plan: closure should start in the beginning of the seventies and should have been finished in 1978. In this way, enough time and learning possibilities were available to develop new technologies.
The Delta Plan thus implied a new technical mission for the regime of coastal barriers and a related pattern of planned innovation. This was not as extraordinary as it may seem. Earlier large-scale coastal barrier projects like the closure of the *Zuiderzee* and the reclamation of *Walcheren* had also been carried out at the edges of what was considered technically feasible.[14] The formulation of new technical mission and related patterns of 'planned innovation' was historically not a new phenomenon in the regime of coastal barriers. Therefore, the Delta Plan was not a break with the existing regime of coastal barriers.[15]
There is another reason to see the Delta Plan as a continuation of the existing regime of coastal barriers. The design criteria for the Delta Plan did not differ much from those generally accepted in the regime of coastal barriers.[16] Safety was a prime

design criterion.[a] Criteria like shipping and fighting salinity and improving fresh water supply were not exceptional too.
From the start of the Delta Plan, it was recognized that the closure of tidal inlets would have not only advantageous secondary effects - like fighting salinity, improving fresh water supply and improving road connections - but also disadvantageous ones: it would frustrate salt water fishing and ruin the existing mussel and oyster firms, especially in the *Oosterschelde*. In the fifties, the possibility of a normally open but closable barrier in the *Oosterschelde* was considered as a way to save the oyster and mussel cultures. The idea was rejected because it would imply sluices that would hinder shipping toward the *Westerschelde*, and because the solution would cost more.[17] The negative effects for fishing firms thus became accepted.
In the sixties and seventies, another disadvantage of the closure of especially the *Oosterschelde* closure was articulated: the loss of a piece of ecologically unique nature. This resulted in nationwide protests in the seventies. Eventually, the central government decided to reformulate the mission of the *Oosterschelde* project. The *Oosterschelde* would not be closed off, but a so-called storm surge barrier would be built.

6.1.2 The Decision to Build a Storm Surge Barrier in the Oosterschelde[18]

The congress of the Zeeland Council of the Sciences in April 1967 is often named as the point of departure for protests against the closure of the *Oosterschelde*.[19] At this congress, four hundred proponents and opponents of closure from varying disciplines (ecology, hydrology, economy, agriculture, fisheries, recreation etc.) met.[20] Although most people were convinced that the *Oosterschelde* would be closed, the larger part of the public sympathized with the opponents of closure, especially since it was conveyed that critical employees of *Rijkswaterstaat* were officially ordered to remain silent.[21]
After the congress, more and more groups protested against the closure of the *Oosterschelde*. Environmental groups feared that a unique ecological area would be lost; organizations of salt water fisher firms feared their bankruptcy; water sport groups feared a loss of opportunities for water recreation. These groups, different as they and their considerations were, jointly protested against closure.[22] In the protests, ecological values became a focal point. Ecological arguments had more cogency than the economic well-being of salt water fishers or the particular pleasures of boaters and swimmers.

a It is true that safety was hardly an official argument for the earlier conceived plans for damming up tidal inlets. However, informally it was an important argument. The reason why safety was not officially recognized or named as argument was not because it was considered an illegitimate design criterion (on the contrary) but because Rijkswaterstaat and the government did not want to create the impression that the south-west of the Netherlands was insufficiently protected.

The protests against closure of the *Oosterschelde* were fed by growing scientific evidence of negative ecological consequences. Some of this evidence had already been published in the fifties by organizations affiliated with political parties.[23] In the sixties, the knowledge about the ecological consequences of closure grew further.[24] In 1971, professor Korringa, director of the *Rijksinstituut voor Visserijonderzoek* (Netherlands Institute for Fisheries Research) predicted that closure of the *Oosterschelde* would have major consequences for the amount of fish in the North Sea and the Atlantic Ocean.[25] Important evidence was also gathered by the *Delta Instituut voor Hydrobiologisch Onderzoek* (Institute for Hydrobiological Research).[26] This institute had been established in 1959 to study the Delta area and the ecological developments and changes due to the Delta works.[a]

Opponents of closure did not deny that the safety of the *Oosterschelde* area should be improved. They denied that closure of the *Oosterschelde* was a reasonable option to reach this goal.[27] According to most opponents, the discussion was not about safety, but about the way to reach safety.
Since opponents did not deny the need to improve the safety of the *Oosterschelde* area, they had to propose alternative solutions. Most of them proposed to heighten the dikes as in the case of the *Westerschelde*, a tidal inlet of a size comparable to that of the *Oosterschelde*. Other alternatives were developed too. In 1972, students of the Technical College Delft (*Technische Hogeschool Delft*) proposed a kind of storm surge barrier.[28]

In 1972 protests reached a peak. The closure of the *Oosterschelde* became a national issue. National broadcasts began to pay attention to the environmental aspects of the *Oosterschelde*.[29] Increasingly, the *Oosterschelde* issue was seen as an opportunity to prove that other social and environmental arrangements were possible. In the fifties and sixties, the Delta Works had been one of the symbols of the centuries old Dutch battle against the sea and of the resurrection of the Netherlands after the Second World War. The engineers of Rijkswaterstaat were seen as national heroes. For the younger generations, however, the closure of the *Oosterschelde* became a symbol of one-dimensional materialistically oriented development.
The protests against the *Oosterschelde* were thus partly the result of the changing social tide in the sixties and seventies. Especially the report of the Club of Rome that appeared in 1971 and was well read in the Netherlands drew attention to environmental and ecological issues. Environmental and other groups called the *Oosterschelde* closure a ‘disaster for the Netherlands.’[30]

a The tasks of this institute were purely scientific. Therefore, it could not express an official opinion with regard to closure. Nevertheless, some of its employees were active in environmental groups. Moreover, the findings of the institute were helpful to mobilize public opinion against closure. The institute, for example, found out that about 1350 organisms were living in the *Oosterschelde*; a number that acquired an important symbolic meaning in the discussions about the ecological richness of the *Oosterschelde* (Interview professor Nienhuis, 20 February 1995).

Despite the nationwide protests, the responsible authorities - the Department of Transport and Communications and Rijkswaterstaat - strongly opposed changes in the Delta Plan. After much pressure from parliament in 1970, the Minister of Transport and Communications was prepared to study the desirability of the closure of the *Oosterschelde*. This study was carried out by Rijkswaterstaat and was finished in 1972.[31] In it, Rijkswaterstaat concluded that a departure from the Delta Plan was neither feasible nor desirable.
In 1972, a majority of parliament did not want to slow down the Delta Plan, although left-wing political parties questioned the closure of the *Oosterschelde*. In the same year, the Dutch government was recalled due to an issue not related to the *Oosterschelde*. After the elections, the first left-wing government after the Second World War came in power. This government decided to install a new committee to reconsider the closure of the *Oosterschelde*.[32] In this committee, named after its chairman Klaasesz, an environmental expert, a biologist, a fisheries expert and an economic expert got a seat besides the ‘traditional’ planner and hydraulic engineer.[33] This broad composition of the committee was typical for the approach of the new government with respect to the *Oosterschelde*. This approach recognized both safety and ecology as important (design) criteria. The new government saw the *Oosterschelde* as a multifunctional problem in which several ministries were involved.[34] This enlarged the possibilities of environmental groups to influence governmental policy with respect to the *Oosterschelde*, especially since some ministers had serious doubts about the desirability of closing off the *Oosterschelde*.[35]
On the first of March 1974, the Klaasesz Committee came with a creative compromise between proponents and opponents of closure: a semipermeable barrier.[36] According to Klaasesz, a semipermeable barrier of blocks should first be built and later be replaced by a storm surge barrier. The technical feasibility of this option was a problem as Klaasesz recognized.[37] Rijkswaterstaat believed that the ‘egg of Klaasesz,’ as the solution was quickly called, was technically impossible.[38] Nevertheless, it asked the building contractors and dredging companies, united in DOS, to investigate the possibilities of a semipermeable barrier with blocks.[39] The reason that Rijkswaterstaat delegated this feasibility study was probably that it feared not to be believed by the public if it, known as the defender of the Delta Plan, considered the Klaasesz solution to be impossible.[40] DOS developed, in collaboration with Rijkswaterstaat and Delft Hydraulics a new design: a barrier consisting of caissons and with ‘holes’ between the caissons, later to be replaced by a storm surge barrier.
After 1972, Rijkswaterstaat became increasingly open to the public.[41] Until then, Rijkswaterstaat had been heavily criticized for its uncommunicativeness. It was accused of not listening to the public and of forbidding its own employees to criticize the *Oosterschelde* closure.[42] Around 1972, it began to realize that it had to improve its public image. After the Klaasesz Report, Rijkswaterstaat cooperated loyally in searching for solutions to new technical problems.[43] For example, it did not, formally or informally, try to withhold DOS from generating new initiatives. Later, Rijkswaterstaat developed a new technical option, a permanent barrier with closable caissons. In its official statements, however, Rijkswaterstaat stayed skeptical about the possibilities of a semipermeable barrier. Its assessments with

respect to the technical feasibility, the costs and the time scale of alternatives were rather conservative compared with other actors.[44]

Parallel to the development of technical alternatives, the political discussion about a new mission for the *Oosterschelde* project took place. For a long time, the Dutch government was profoundly divided with respect to the issue.[45] Some ministers like the Minister of Finance and the Minister of Transport and Communications did want to close off the *Oosterschelde* according to the Delta Plan; others were advocates of a semipermeable barrier. No minister proposed to keep the *Oosterschelde* open and to heighten the dikes. This option had disappeared from the political agenda with the Klaasesz Report, although some members of parliament still believed this to be the only acceptable option.
Ultimately, and after much pressure by especially Prime Minister Den Uyl, the government decided to build a storm surge barrier. In November 1974, parliament sanctioned this decision with 75 to 67 votes, if in one and a half year it could be shown that: 1) a semipermeable barrier was technically feasible, 2) the extra costs did not exceed 1.75 billion guilders plus an extra 20% and 3) the storm surge barrier could be ready in 1985.

After the 1974 governmental decision, it was up to Rijkswaterstaat to investigate the feasibility of a storm surge barrier fitting the three dissolving conditions posed by parliament. Within one and a half year, a feasibility study had to be ready.
The technical feasibility study of the storm surge barrier required the mobilization of a lot of new knowledge from inside and outside Rijkswaterstaat.[46] Therefore, the new head of the Delta Department, Engel, considered it necessary to create a new project organization for research on the storm surge barrier.[47] In this project organization also the Department Sluices & Weirs, the Department Bridges, and the Department Water Management and Water Movement of Rijkswaterstaat were to participate. The united dredging companies and the research institute Delft Hydraulics also played an important role in the research and design efforts within the project organization.
The work inside the project organization was characterized by two developments.[48] First, a large number of alternatives was generated. Second, the rivalry between the Delta Department and the Department of Sluices & Barriers increased. Initially, the project organization was organized around constructions with closable caissons, which was in line with the decision of parliament. Also other types of solutions were proposed in the various working groups. In June 1975, for example, 324 combinations of possibilities were under discussion. Engel continuously tried to promote the development of new alternatives. Therefore, he was striving for a more flexible project organization. Blokland - the head of the Department of Sluices & Barriers, a department that had played an important role in the realization of the Delta Works and had much experience with caissons - heavily opposed Engel's attempts to change the project organization. In the end, Engel won the quarrel. His success was partly due to his better access to the head of Rijkswaterstaat and the Minister of Transport & Communications, and partly to doubts within the project organization about the technical and economic feasibility of a solution based on caissons.

Rijkswaterstaat had to report parliament on the feasibility of a storm surge barrier in May 1976. At that moment, three serious alternatives were available: pillars funded on pits, which was supported by the Delta Department, caissons funded on sand, supported by the Department Sluices & Barriers, and caissons funded in pits. The main thing known was that for all these alternatives meeting the conditions that parliament had formulated in 1974 would be hard, but not necessarily impossible. In the feasibility study, a preference was spoken out for 'pillars on pits,' an alternative presented as meeting the conditions formulated by parliament.[49]
In May 1976, Rijkswaterstaat sent the government the feasibility study, which became popularly known as the Blue Memorandum due to its blue cover. With this memorandum, Rijkswaterstaat sent the government the so-called White Memorandum. This memorandum made an assessment of different plans with respect to what by then were seen as the main design criteria, safety and the environment, and less important considerations (related to secondary effects) like costs, fisheries, economic consequences, etcetera.[50] In the White Memorandum, three alternatives were compared: a storm surge barrier, an open *Oosterschelde* (with higher dikes) and closure according to the Delta Plan.[51] (For the assessment of the ecological consequences, see Box 6.1).[52]
The White Memorandum had started as a personal initiative of Engel. The reason Engel commissioned an assessment study was that he feared that the storm surge

Box 6.1 *Prediction of Ecological Consequences in the POLANO-Study*

One important aspect in the policy analysis of the *Oosterschelde* was the prediction of the ecological consequences of the three alternatives: the storm surge barrier, closure and an open *Oosterschelde* with higher dikes. Rand's aim was not to answer all scientific questions concerning the ecological consequences of the three alternatives. It wanted to develop a model of the ecosystem that helped in articulating a political decision, instead of replacing such a decision. Moreover, it felt that the 'traditional' ecological modeling approach had failed. This traditional approach aimed at developing dynamic models of ecosystems like the *Oosterschelde*. Instead, Rand tried to predict the long-term stable state of the *Oosterschelde* ecosystem. For this purpose, Rand developed the so-called *General Ecomodel*.
None of the Rand people had a specific background in ecology, although some had substantial experience in biology. The *General Ecomodel* was based on Rand's tradition in systems analysis and operations research and on the personal experiences of the researchers involved. It appears that the idea of a *General Ecomodel* was particulary based on a 'chemical equilibrium model' developed by one of the Rand co-workers. The *General Ecomodel* enabled the Rand researchers to predict the ecological consequences of the various *Oosterschelde* alternatives. One assumption was specially important in this prediction. On the basis of the available data, the Rand researchers assumed that the *Oosterschelde* was a detritus importing estuary. This meant that closing off the *Oosterschelde* or reducing its aperture would influence the amount of biomass in the *Oosterschelde* ecosystem. Indeed, the final Rand Report, which appeared in December 1977, concluded that a closed *Oosterschelde* or a storm surge barrier (SSB) with an aperture of less than 6,500 square meters would reduce the amount of biomass. The Rand Report also stated that 'ecological considerations may help one to reject the closed case,' but given the uncertainties, 'they do not strongly distinguish between the open case and the storm-surge barrier case in which the aperture exceeds 6500 square meters.'
The Rand Report thus legitimized the choice for a storm surge barrier from an ecological point of view. The Rand Report also investigated the consequences of the three alternatives in terms of safety, costs, economy, fisheries, etcetera. This showed that the open case was the least preferable from the safety point of view. So, the storm surge barrier could be seen as the acceptable compromise.

barrier might be too expensive.[53] In that case, parliament might not simply fall back on the original plan: closing the *Oosterschelde*. Therefore, alternatives should be available or there should be *new* arguments for closure. Apart from such considerations, the choice for the storm surge barrier would be more convincing if it were not only based on technical grounds.
The research for what later was called the White Memorandum was carried out by the American Rand Corporation, a well-known think-thank in policy analysis.[54] The study of Rand has become known as the POLANO-study (Policy Analysis Oosterschelde). Originally, the possible outcomes of the POLANO-study were not meant to be published officially; Rand and Rijkswaterstaat worked silently on the study.[55] Since neither parliament nor the minister had asked for a policy analysis, Engel had had to convince the formal head of the Delta Department, Ferguson, the director-general of Rijkswaterstaat and the minister of the need to have a policy analysis carried out. They allowed him to do so if no publicity was given to the study.[56]
When the results of the Rand study became available, the question became what to do with them.[57] After various questions on the *Oosterschelde* in parliament, the Minister of Transport and Communications became increasingly convinced that presenting the results of the study might be prudent. Since the study did not delegitimize the existing compromise (the storm surge barrier), it would do no harm, and, inevitably, the existence and the outcomes of the study would become public. So, in March 1976, Rijkswaterstaat started working on the White Memorandum that was to present the outcomes of the policy analysis to parliament.[58]
In May 1976, the White Memorandum appeared. It did not speak out a preference for any of the alternatives, but the results supported the view that the storm surge barrier would be the best compromise between the criteria of safety and ecology.

In June 1976, government and parliament had to choose what to do with the *Oosterschelde*. A few months earlier, an open Oosterschelde had returned to the political agenda. In April 1976, a report appeared that stated that heightening the dikes was technically feasible, much cheaper and quicker to realize than a storm surge barrier. The report was written by the consulting engineering firm DHV and ordered by various environmental groups. Also two other options, besides the storm surge barrier, were on the political agenda: closure according to the Delta Plan and building a ‘reductor.’[59] Nevertheless, government and parliament decided to stick with the storm surge barrier.

6.1.3 A Demand Upon Ecologists

The 1976 government decision to commission a storm surge barrier definitively meant the re-formulation of the mission of the *Oosterschelde* project. Now it was up to Rijkswaterstaat to solve the remaining technical problems.[60] Rijkswaterstaat and the dredging companies again formulated a new project organization. The chosen option ‘pillars on pits’ evolved to ‘monolith pillars funded on sand.’[61] A number of technical innovations were achieved by Rijkswaterstaat and its partners. Such

innovations in themselves did not imply a departure from the existing technological regime of coastal barriers and its mission-oriented innovation pattern.[62] Like the Delta Plan and earlier projects for coastal barriers, the new mission of the *Oosterschelde* project was formulated by Rijkswaterstaat together with the central government. Like earlier projects, it was formulated at the edges of what was considered technically feasible at the time.
The main way in which the decision to build a storm surge barrier, and the actual design of the barrier, departed from the existing technological regime was the important role of public pressure in the decision to build a storm surge barrier and the growing emphasis on ecological design criteria. The first was discussed in the preceding section. The second will be discussed below. As we will see, emphasis on ecological criteria in the design and construction of the storm surge barrier resulted in a demand upon biologists and ecologists.

The first full recognition of ecological concerns as serious (design) criteria came with the composition, and later the report, of the Klaasesz Committee. The following POLANO-study and the White Memorandum were somewhat belated attempts to optimize the design criteria safety and ecological care. Belated, because the decision to build a storm surge barrier had, more or less, already been made. Nevertheless, the POLANO-study of Rand suggested a role for ecologists and biologists with respect to important (design) decisions in the *Oosterschelde* project.[63] The POLANO-study was followed by several other policy analyses for the *Oosterschelde* project in which ecological concerns and ecologists played a role.
Especially the Environmental Division of the Delta Department became an important vehicle for ecologists to acquire a more important role in the *Oosterschelde* project and eventually in the technological regime of coastal barriers.[64] This Environmental Division was established at the Delta Department in 1971.[65] It was to carry out or commission research on the ecological consequences of the Delta works, and to develop management strategies for the area after closure. Initially, this research was not considered relevant for the design of the construction works by Rijkswaterstaat. Ecological care was not yet recognized as a legitimate *design* criterion. Ecological considerations were ‘only’ to influence the later management of the area.
After the decision to build a storm surge barrier, the Environmental Department came to play a more important role in the design and construction of the storm surge barrier. This role was partly due to the societal pressure on Rijkswaterstaat to give more weight to ecological considerations, and to the legitimating function of the Environmental Division in this respect.[66]
The Environmental Division also tried as much as possible to be an acceptable partner to the other divisions.[67] It did so by presenting itself as a division consisting of ‘objective’ but pragmatic experts. Its objectivism speaks from *Driemaandelijks Bericht Deltawerken*, a periodical bulletin of the Delta Department: ‘... the Environmental Department has always meant to present itself not primarily as an interest group, but as an agency that provided objective knowledge about the environment.’[68] Its pragmatism speaks, among other things, from the fact that it did not only or merely reject existing plans, but often took these plans as point of departure for achieving ecological values.[69] Sometimes, this pragmatism led to

tensions with scientists, who carried out research for the Environmental Division,[70] but this attitude must have made the division more acceptable to the (civil) engineers of Rijkswaterstaat.

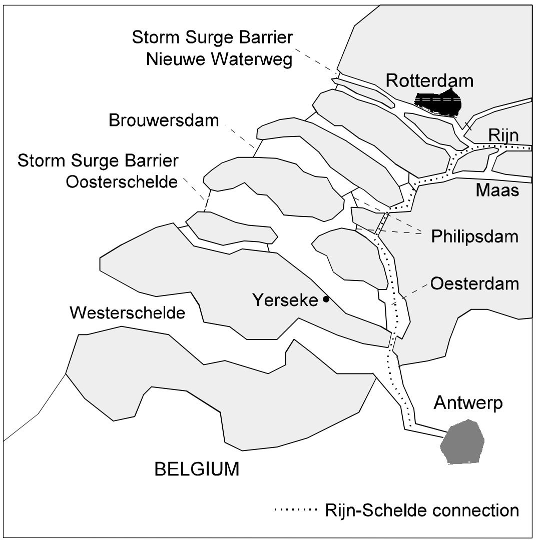


Figure 6.2 *The Delta Area in 1997*

Despite the objective and pragmatic attitude of the division, many conflicts between the Environmental Division and other divisions took place. Some civil engineers even called the Environmental Division the 'Green Maffia.'[71] Partly this may reflect the different cultures and preferences of civil engineers and ecologists. Partly, it is also due to the fact that the Environmental Division tried to influence important decisions with respect to the design and construction of the storm surge barrier in an ecologically more optimal direction.[72] Below, I discuss four instances in which ecologists played a role in important decisions with respect to the storm surge barrier. These decisions are: 1) the decision about the magnitude of the aperture in the storm surge barrier; 2) the decision about the closing strategies of the barrier in relation to the design of the barrier; 3) the role of ecological concerns during the final construction works and 4) ecological monitoring for the later management of the area.

The Magnitude of the Aperture in the Storm Surge Barrier[73]

Ecological concerns played an important role in the stipulatation of the magnitude of the aperture in the storm surge barrier. The ecological significance of this magnitude was twofold. First, it determined the mean tidal volume and consequently the salinity of the estuary. Salinity had to have a minimal value for ecological reasons. Second, it influenced the vertical tide. A decrease in the vertical tide would diminish the area of the so-called intertidal flats, a very valuable part of the *Oosterschelde* ecosystem.

The requirements for salinity and for the vertical tide at *Yerseke* were translated into an aperture for the storm surge barrier with the help of a mathematical tidal model. With this model it was estimated that the aperture of the storm surge barrier had to be at least 11,500 square meters.[74] Earlier, Rand had suggested that a smaller aperture (6,500 square meters) might suffice.[75] According to the Rand Report, the choice for a larger aperture or an open *Oosterschelde* depended on the formulated goal for ecology. An aperture between 6,500 and 11,500 square meters would optimize the total biomass, but imply 'a shift in relative abundances from the present situation in favor of noncommercial bottom species, such as snails and worms. Also, the transient period would be longer and would perhaps include some objectionable

ecological transients.'[76] So, '[i]f the goal is to minimize the change from the present situation ecology, the preference will be the open case or an SSB case with a large aperture (20,000 sq. m). But if the goal is solely to maximize total biomass, one should prefer an SSB case with an aperture between 6500 and 11,500 sq. m.'[77]
The 1976 *White Memorandum* did not mention these suggestions.[78] The 1976 *Blue Memorandum* on the feasibility of a storm surge barrier stated:

> *The progress of the environmental research does not make it possible yet to give an exact quantification of the ecological consequences resulting from a change in the tidal regime.*
> *For this reason, not only a storm surge barrier based on an aperture of 11,500 m^2 has been investigated, but also a design based on an aperture of 20,000 m^2.*[79]

It was estimated by Rijkswaterstaat that an aperture of 20,000 square meters implied a vertical tide of 3.1 meters at *Yerseke* (see Table 6.1), but such a choice would cost an estimated 260 million guilders extra. While this was not a huge amount given the total costs of the storm surge barrier, it might imply that the barrier could not meet the financial condition formulated by parliament in 1974. Indeed, when parliament in 1976 decided to commission a storm surge barrier, the extra costs for an aperture of 20,000 square meters were considered unacceptable. The parliamentary decision, nevertheless, left room for an aperture between 11,500 square meters and 20,000 square meters.
The government now installed an interdepartmental working group to study three alternatives: 11,500 square meters, 14,000 square meters and 20,000 square meters, implying an estimated vertical tide of respectively 2.3, 2.7 and 3.1 meters at *Yerseke*. Not accidentally, 2.7 meters was exactly the mean of 2.3 and 3.1 meters. In September 1977, parliament chose an aperture of 14,000 square meters.
The way this political decision was interpreted by Rijkswaterstaat (and the other parties responsible for the design of the storm surge barrier) shows that ecological considerations had indeed attained a more important role.[80] The project group working on the storm surge barrier interpreted the political decision as implying the

Table 6.1 *Relation Between Magnitude of Aperture in the Storm Surge Barrier and Reduction in Tide*

	11,500 m^2	14,000 m^2	20,000 m^2	Open Ooster-schelde (80.000 m^2)
Mean vertical tide at Yerseke	2.3 m	2,7 m	3,1 m	3.5 m
Reduction in vertical tide	35 %	25 %	10 %	-
Mean tidal volume	675 mln. m^3	800 mln. m^3	925 mln. m^3	1250 mln. m^3
Reduction in tidal volume	45 %	35 %	25 %	-

need to ensure the largest possible chance that the mean tide would not fall below 2.7 meters. This meant that 14,000 square meters was taken as the *nett* aperture. This number was multiplied by a factor so as to account for the resistance of the barrier. Moreover, amounts were added so as to account for other expected losses and uncertainties. The result was that an aperture of 18,000 square meters was taken as point of departure for the design. At that moment, it was estimated that this would imply a mean vertical tide at Yerseke of 2.8 meters, with a worst case scenario implying a mean vertical tide of 2.7 meters. Estimates, made in 1982 and 1984, showed a resulting mean tide at *Yerseke* well above the 2.8 meters.

The BARCON-Study[81]

Ecological insights did not only play a role in establishing the requirements for the aperture of the storm surge barrier. They were also important for the formulation of other requirements with respect to the storm surge barrier.
In 1977, the Barrier Control (BARCON)-project started. The project was to formulate requirements for the design of the storm surge barrier given its intended use and to carry out a policy analysis of the various closing strategies. The project was carried out in cooperation with the Rand Corporation. Like for the POLANO-project, alternatives were evaluated in terms of safety, ecology, costs, shipping, fisheries, etcetera. It turned out that for both safety and ecological reasons, it was desirable that the barrier design allowed for different closing strategies.
Three closing strategies were possible. First, complete closure at a specific stagnant internal water level (inner water level strategy). Second, complete closure with allowing for the possibility to open the storm surge barrier between two predicted storms (alternating strategy). Third, partial closure to reach a reduced tide in the

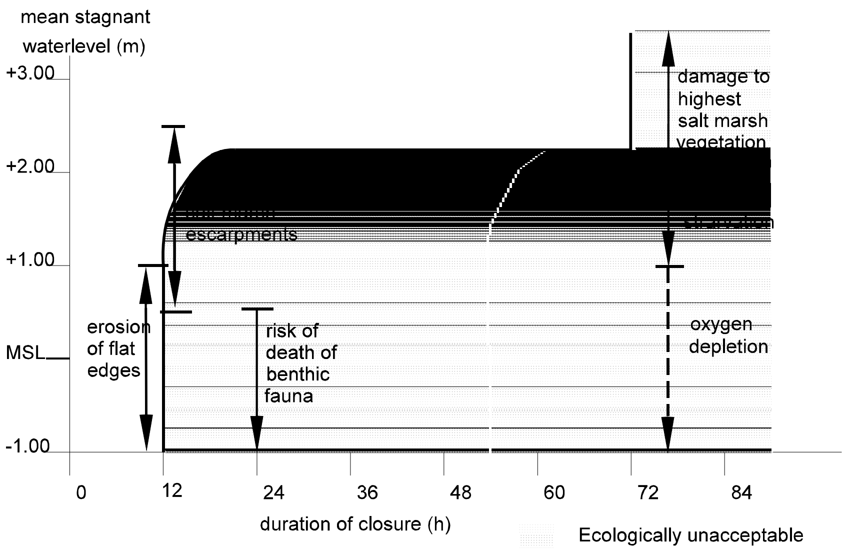


Figure 6.3 *Relation Between Duration of Closure, Mean Stagnant Water Level and Ecological Consequences*

Oosterschelde (reductor strategy).
Especially for the first two strategies different choices could be made about the actual inner water level. Ecological studies had shown that only a limited number of combinations of inner water levels and durations of stagnation were acceptable (see Figure 6.3). These studies played an important role in the final choice of a closing strategy.
In 1986, it was decided to use the 1-2-1 alternating closing strategy. This means that the internal water level is fixed at Mean Sea Level (MSL) plus one meter at the first predicted storm peak, at MSL plus two meters at a possibly following second peak, and again at one meter plus MSL if a third connected storm peak is expected.

Ecological Considerations During the Construction of the Storm Surge Barrier[82]

Between 1985 and 1987, a number of gates of the storm surge barrier were closed incidentally for the final construction of the storm surge barrier and to facilitate the closure of the partition dams. (For the partition dams see Box 6.2). Closing the gates during construction work was advantageous for both hydraulic and financial reasons, but it was expected to be ecologically harmful as well as unfavorable for the shell fisheries.[83]
The ecological consequences of temporal closure might even be irreversible according to ecologists. Therefore, boundary conditions were formulated for the closure of the gates during construction. These conditions were based on earlier ecological investigations carried out for the policy analysis and the design of the storm surge barrier. They implied that the tide at *Yerseke* could not be allowed to fall below 2.3 meters. An expectation was made for the final construction period. However, in this period, the barrier should never be entirely closed for longer than two days.
Another point at which constructive and ecological considerations conflicted was the question in which season the partition dams were to be completed. Completing the works during the winter season was undesirable from a hydraulic engineering point of view. Completion of the works in summer was probably ecologically most harmful. As a compromise, it was decided to finish the partition dams in autumn or spring.
During the final construction of the works, when the new tidal regime was to be

Box 6.2 *The Partition Dams*

Due to the decision to build a storm surge barrier, the *Oosterschelde* would remain saltish. This created problems for the fresh water economy of the Provinces *Noord-Brabant* and *Zeeland*. Moreover, a 1963 treaty between the Netherlands and Belgium ordered that the connection between the *Rijn* and the *Schelde,* which crossed the *Oosterschelde,* had to be free of tidal influences. Therefore, dividing the Oosterschelde in a salt and a fresh part was necessary.
Partitioning the *Oosterschelde* could be done in many different ways. The Klaasesz committee had summed up more than thirty varieties in its 1974 Report. In December 1974, the Committee Partitioning Oosterschelde (*Commissie Compartimentering Oosterschelde*) was established. Its task was to review various possible partitions in the light of the consequences for agriculture, fisheries, the environment, the landscape, shipping, planning and in terms of costs, techniques and time schedules. In April 1975, it advised the building of two partition dams: the *Philipsdam* and the *Oesterdam* (see Figure 6.2). These two dams were built between 1977 and 1987.

established, several ecological variables were carefully monitored to detect possible negative ecological consequences. Occasionally, this influenced the closing strategy for the barrier during the final construction phase. In October 1986 and January 1987, for example, the storm surge barrier was used to enlarge the available foraging area for birds to prevent many of them from dying.

Ecological Consequences of the Storm Surge Barrier[84]

With the decision to build a storm surge barrier, ecological concerns and ecologists got a more important role with respect to the design of the barrier. Nevertheless, their most important contribution (still) would be during the period after the construction of the barrier. In this period, they would give advice about the actual closing strategies of the storm surge barrier and the management of the *Oosterschelde* area.

In 1980, researchers of the Environmental Division of the Delta Department and the Delta Institute for Hydrobiological Research started the BALANS-project, an ecosystem study with the aim to analyze the response of the *Oosterschelde* ecosystem to the changing circumstances; the results were to be used for the future management of the area. The BALANS-project ended in 1987 and was followed by the EOS-project that lasted until 1991. In that year, several evaluations were published by Rijkswaterstaat, including a report dealing with the observed ecological developments in the *Oosterschelde* estuary.

To predict and monitor the ecological consequences of the storm surge barrier, the model SMOES (Simulation Model *Oosterschelde* EcoSystem) has been developed. According to the researchers, the response of the *Oosterschelde* ecosystem to the changes in its physicochemical environment has been resilient and robust (see Box 6.3).[85] This positive result was probably due to the larger than expected remaining vertical tide and the positive developments in water quality. Moreover, at the end of

Box 6.3 *Ecological Consequences of the Storm Surge Barrier*

The ecological consequences of the storm surge barrier are related to the resulting tidal difference, resulting flow rates, water quality and geomorphological adjustment processes.
The resulting *tidal difference* at *Yerseke* is more than the required 2.7 meters. It has been estimated that the resulting vertical tide is about 3.25 meters. (A part of the increase is due to a new calculation method).
The *flow rates* in the *Oosterschelde* have been reduced as a result of a lower fresh water load from the rivers *Rijn* and *Maas* (minus 80% due to the partition dams) and a declined water exchange with the *Noordzee* (minus 28% due to the storm surge barrier). Combined with the fact that the area will not suffer any longer from huge storm floods, this has resulted in more sheltered circumstances and changed the *Oosterschelde* from a turbid estuary into a tidal bay.
With respect to *water quality*, conditions have improved. Salinity has not decreased as initially expected, but increased somewhat. The already low level of micropollutants has fallen further due to the reduced water inflow from the (polluted) rivers *Rijn* and *Maas*.
A number of *geomorphological adjustment* processes are taking place in the *Oosterschelde* basin since the construction of the storm surge barrier. These processes will probably last more than a hundred years. The gullies in the new tidal bay are too deep given the reduced flow of water. This results in sedimentation of the gullies and erosion of the intertidal flats and salt marshes. The area of intertidal flats has already dropped by more than 30% since to the construction of the storm surge barrier. A further decrease of about 15% is expected for the coming thirty years.

the eighties, the *Oosterschelde* turned out not to be a detritus importing estuary as the POLANO Report had supposed (*cf.* Box 6.1).
It is very hard to say whether the response of the *Oosterschelde* ecosystem will remain robust. Especially the erosion of the intertidal flats may pose a serious threat. The *Zeeuwse Milieufederatie*, a local environmental group, has already stated that the nett ecological consequences of the storm surge barrier are, therefore, detrimental. To 'solve' the problem, the group has pleaded for giving back polders to the sea, without success.

6.1.4 Transformations of the Technological Regime of Coastal Barriers; Toward Integrated Water Management

In the preceding section, we have seen how ecologists and biologists contributed to the *Oosterschelde* project by supplying knowledge in the form of design requirements and assessments of ecological consequences. This knowledge could relatively easily be incorporated in the civil engineering design approaches of the existing technological regime. However, during the *Oosterschelde* project, also a new design approach developed. This new approach differed in several respects from the 'traditional' civil engineering design approaches.[86] One element was that ecological criteria were taken more seriously.
For influential people at the Environmental Division of the Delta Department, taking serious environmental and ecological design criteria did *not* necessarily mean the conservation of existing nature. Saeijs, a former head of the Environmental Division, for example, has suggested that at the Environmental Division the storm surge barrier was defined as an ecological challenge rather than as an ecological threat.[87] Partly, this may have had strategic reasons. It made the Environmental Division more acceptable to other parts of the Delta Department and Rijkswaterstaat, since the storm surge barrier was accepted as a given fact. Meanwhile, this definition opened possibilities for steering the process of design and construction, since it could be argued that design and construction decisions were ecologically and environmentally relevant.
The definition of the storm surge barrier as ecological challenge may also be interpreted as part of the tendency among (some) ecologists to argue for more offensive approaches to nature management.[88] Such a plea may be inspired by visions of primaeval nature, in which man does not play a role. Man should bring about the circumstances in which primaeval forms of nature can return and flourish.[89] An offensive approach to nature management may also be motivated by a 'radical' man-inclusive vision of nature, *i.e.* a vision of nature in which interference of man is natural and inescapable.[90] Nature development is not (only) something to be striving for, but (also) something continuously taking place. The challenge is to steer ecological developments in the right direction.
The latter man-inclusive vision of nature seems to underlie the definition of the storm surge barrier as 'ecological challenge.'[91] Especially the aforementioned Saeijs has explicitly contrasted this attitude with existing conservationist approaches like approaches based on Environmental Impact Statements (EISs):

The EIS approach has become in practice defensive in nature and is an example of a method consistent with a strategy of 'reaction' ... it does little to bring us any closer to a solution to a problem which quite clearly affects society, namely that society is undergoing change and wishes to progress. Any society is always in the throes of change and undergoing a process of development. ... The point is not to swim against the tide of change, even if that were possible, but to guide the processes of change along the right lines. The crucial question is how to monitor the process of change in estuaries in a socially, and therefore ecologically, acceptable manner.[92]

In his dissertation *Changing Estuaries; A Review and New Strategy for Management and Design in Coastal Engineering*, Saeijs argues that monitoring and steering the process of ecological change requires 'an integrated systems approach.'[93] Such an integrated approach implies an integral consideration of the whole area affected. This implies taking into account the various *functions* the area has to fulfill. These functions include nature, recreation, shipping and drinking water.
Such a multifunctional approach also underlaid Rand's policy analysis and the White Memorandum.[94] In both, alternative options were compared with respect to the various functions of the *Oosterschelde* area. The approach was also applied to the aperture study, the BARCON-study and the partition dams study.[95]

The approach developing during the *Oosterschelde* project can be best described as *integrated water management*. Integrated water management finds it background in the *Oosterschelde* project and in developments with respect to fresh water management. Since the mid eighties, integrated water management increasingly has become the point of departure for government policy with respect to water management (Box 6.4).[96]
In integrated water management, the water system is taken as starting point.[97] Central are the harmonization of the various functions of the water system, the development of the potentials of the water system and the differentiation of management tools for water systems.[98] The water system is defined as the water, the banks, the (ecological) living communities and human use.[99] This water system is more encompassing than both the traditional objects of civil engineering and ecology. Civil engineering traditionally focused on technical objects and not on the more encompassing systems in which these objects have to function.[100] Ecologists traditionally concentrated on living communities or ecosystems (also including abiotic components). While a focus on water systems is compatible with concern for the relevant ecosystem, it is also broader because also other functions of the water system like shipping and recreation are relevant.[101] Moreover, integrated water management also includes an integral approach to policy making and water management.[102]
Integrated water management in principle attributes the same status to ecological functions as to other (potential) functions of the water system, like drinking water, safety, shipping and recreation. In concrete cases, the administrator of the water system usually has to make a choice between these functions. This implies that in concrete cases ecological functions and design criteria may hardly play a role. Nevertheless, integrated water management implies that interventions in the water

system should be 'ecologically fit.'[103] What 'ecologically fit' means will often not be immediately clear. Ecologists and other environmental experts should assess what 'ecologically fit' meant in a particular case. Therefore, integrated water management requires an involvement of ecologists. Ecologists should 1) formulate the requirements for the sustainable subsistence of different water ecosystems, 2) determine the effects of combinations of (user) functions on the sustainability of the ecosystem and 3) design forms of management for the sustainable subsistence of ecosystems and the harmonization of functions.[104]

An integrated water management design approach implies three changes in the design of coastal barriers. First, integrated water management implies that the functions of coastal barriers and the related design criteria can no longer simply be taken for granted. Safety will often be an important but not the only design criterion. Ecological considerations should at least be taken into account. In each concrete case or project, a strategic or even political decision should be made about which functions, which design criteria are important.[105] Compared with the past, this means that the formulation of the design requirements becomes more extensive and encompassing.

The second change implied by an integrated approach is that coastal barriers should not simply be designed as technical objects, but as 'management tools' that have to function within a more embracing water system. Especially Saeijs has stressed this shift. According to him, coastal barriers and other hydraulic works should be

Box 6.4 *Integrated Water Management*

In 1985, the governmental memorandum *Omgaan met Water* (Living with Water) appeared. This document is often seen as *the* turning point toward integrated water management. It was mainly written by Saeijs, a former head of the Environmental Division of the Delta Department. The memorandum was accepted by parliament after enduring resistance from the shipping sector, which rejected ecological considerations finding equal footing with nautical requirements.

The integrated water management approach is based on the *Oosterschelde* project and developments in fresh water management. Until the early seventies, fresh water management mainly concentrated on safety and quantity issues like the availability of water and water level management. The first Dutch Memorandum on Water Economy (*Nota Waterhuishouding)* of 1968 was written in the spirit of such considerations.

In the seventies, increasingly attention was paid to the water quality of fresh water. Important legal and policy documents that reflect this trend are the Pollution of Surface Water Acts (1970) and the three Water Action Programs or IMP's (*Indicatieve Meerjarenprogramma's*) formulated to combat water pollution.

In time, attention shifted from an approach emphasizing standards for single pollutants to an approach taking the complete water ecosystem as starting point. This shift is visible in the Second Water Action Program (*IMP Water 1980-1984*). Also in the 1984 Second Memorandum on the Water Economy (*Tweede Nota Waterhuishouding)* which mainly dealt with quantitative water management, attention was paid to the integration of quantitative and qualitative issues. In the Third Water Action Program (*IMP 1985-1989*), attempts were undertaken to define ecological norms for water quality.

In 1988/1989, the Third Memorandum on the Water Economy (*Derde Nota Waterhuishouding)* appeared. In this document, integrated water management became the official point of departure for water management in the Netherlands. A water systems approach was advocated. This implies, among other things, the taking into account of the various functions of a water system and the integration of quantity and quality considerations.

designed to function properly in the water system, in which several functions have to be fulfilled.[106] The effects of the coastal barriers should be closely monitored as to manage the induced transformation processes. An integral policy plan for the whole area should be formulated as to manage the ongoing changes and, in the ideal case, the hydraulic works should be used as management tools to steer the process of transformation in the area.
Related to the first two changes is a third change. Integrated water management implies a structural role for new professional experts, like ecologists, biologists, landscape gardeners and recreational experts in the technological regime of coastal barriers.[107] In the different phases of the design process they will play different roles. A 1981 article in the *Driemaandelijks Bericht Deltawerken* discusses the role of ecologists in four different phases in the design of coastal barriers.[108] These phases are preparation, design, construction and maintenance. In the first phase, a policy analysis should be made. In this phase an extensive knowledge of the relevant ecosystem, and so input from ecologists, is required to assess the possible ecological consequences of the project. During the second and third phase, *i.e.* design and construction, technical aspects prevail. Nevertheless, involvement of ecological and environmental experts is essential to forestall as much as possible negative ecological and environmental consequences. Ecological experts formulate requirements or boundary conditions. In the fourth and final phase - maintenance of the barrier and management of the area (water system) - ecological experts are to play a prominent role.

Recently, integrated water management has been laid down in several policy documents (Box 6.4). Important actors in the regime of coastal barriers like Rijkswaterstaat, the engineering firms and the research institute Delft Hydraulics have accepted the striving for integrated water management, and the importance of ecological design criteria. These organizations also have begun to employ an increasing number of ecologists.[109]
On a more concrete level, the effects of the striving for integrated water management are more difficult to trace. In recent years, one coastal barrier project has been undertaken in the Netherlands.[110] At the end of the eighties, it was decided to build a storm surge barrier in the *Nieuwe Waterweg*; the main functions to be fulfilled were safety and shipping.[111] A storm surge barrier was chosen because this was cheaper

Box 6.5 *The Westerschelde and Integrated Water Management*

In the Delta plan, it was decided to heighten the dikes of the *Westerschelde* so as not to frustrate the shipping route to *Antwerpen*.
Initially, environmental considerations for the *Westerschelde* area were merely confined to water pollution; only recently more attention has been paid to the functioning of the ecosystem as a whole. Meanwhile, shipping and ecological criteria have increasingly begun to conflict. The conflict became particularly clear in 1995 when Belgium and the Netherlands signed a treaty about the *Westerschelde*. This treaty implied the removal of sand banks in the *Westerschelde* to ease shipping. Environmental groups fear that this decision will have major adverse ecological effects. Rijkswaterstaat has proposed to compensate the adverse ecological consequences by giving back polders to the sea. However, the *Zeeland* population recently spoke out against this option at several information meetings. Rijkswaterstaat is now reconsidering compensatory measures.

than heightening the dikes and meant that no buildings - especially in Rotterdam - had to be broken down. Moreover, the project would be finished earlier in this way. Ecological considerations hardly played a role in the project. This does not *per se* mean that this project does not fit within the integrated water management approach. As we have seen, the integrated water approach implies that a conscious decision *can* be made *not* to include ecological functions in a particular project.
An indirect way to evaluate whether the integrated water management approach has been put in practice is to look at recent coastal *projects* in the Netherlands. Such projects are not carried out within the regime of coastal barriers. Nevertheless, they tell something about transformations in this regime because in coastal projects largely the same kinds of actors and the same kind of (conflicting) functions and interests play a role.
An example of an important recent coastal project is the *Westerschelde*.[112] This project, as explicated in Box 6.5, shows two things. First, it underlines the commitment of Rijkswaterstaat to the striving for integrated water management. Second, it makes clear that implementing integrated water management in concrete cases may be difficult because it conflicts with existing interests and values.

Problems with the implementation of integrated water management are not specific to the technological regime of coastal barriers, but apply to integrated water management in general.[113] We will now look and see how this worked out in another technological regime in the area of water management, the regime of waterside banks protections. In this regime, a new design approach for ecologically sound banks - that was in line with the striving for integrated water management - was articulated in the mid eighties.

6.2 Waterside Banks Protections

The Netherlands is known as a country of water. It not only has a relatively long coast line and several large rivers flowing through, but also a large number of smaller waters like canals, brooks, lakes and ditches. The total length of waterside banks in the Netherlands amounts to some hundreds of thousands of kilometers.[114] Traditionally, most of these banks were not artificially protected against the water, and many still are unprotected. However, it was often deemed necessary to protect waterside banks artificially against erosion or floods. This has led to a number of constructions for bank protections.[115] The main function of such bank protections is to maintain the boundary between the water and the land.[116]
The design and construction of waterside banks and bank protections are related to the design and construction of waterways. Some waterways, like canals and ditches, are artificially constructed; others, like rivers and brooks, have a natural origin. During the nineteenth and twentieth century, many natural waterways in the Netherlands were channeled to ease shipping and water transport.[117] This has decreased the natural dynamism of rivers and brooks and their landscape scenic and ecological values.

In the twentieth century, hard substrates like stones, rubble and concrete were increasingly used to reinforce banks or to build waterside bank protections.[118] The use of such materials was often motivated by increasing erosion of existing waterside banks. This erosion was mainly due to more rapid water transport and heavier shipping, which were enabled by the earlier channeling of waterways.
The use of hard substrates for water bank constructions further decreased the ecological and landscape scenic values of banks.[119] Increasingly, natural banks like reed-banks were replaced by constructions consisting of stone, wood and synthetic materials. This (secondary) effect of the technological regime of waterside banks was made manifest by outsiders like biologists, ecologists, environmental organizations and recreational organizations.

In 1979, the Natural Science Committee of the Dutch Council for Nature Conservation published a report on the 'unnoticed deterioration of the banks of the large rivers due to the use of hard substrates like concrete and stones'[120] The report argued that ecological design criteria should become more important in the design of bank protections. Other types of constructions consisting of other materials should be built. Further, it was argued that ecological and environmental knowledge - as it existed at the Natural Science Committee and Rijkswaterstaat - should be used during the construction, reparation and maintenance of waterside bank protections. The report of the Natural Science Committee was a first attempt to make ecological design criteria more important in the technological regime of waterside banks. It was followed by the establishment of the cooperative body *NIR (Please ... not in the reed!)* in 1983.[121] This body consisted of three ministries and nine organizations active in the area of recreation, nature and environmental conservation, and water and bank management. Initially, the NIR merely tried to conserve existing reed-banks. Later, it also tried to make ecological design criteria more important in the design of waterside banks. In 1990, the NIR published a guidebook on the construction and maintenance of ecologically sound banks.[122] The goal of the guidebook was 'to win the administrators of waterside banks for ecologically sound banks, in which reed will often play a dominant role.'[123]
In reaction to these initiatives and political attention for the issue, Rijkswaterstaat formulated the Project Ecologically Sound Banks or PMO (*Project Milieuvriendelijke Oevers*) in 1985.[124] Rijkswaterstaat was and is one of the most important actors in the regime of waterside banks. It administers the larger waterways in the Netherlands and carries out and commissions research on waterside banks. With the formulation of the PMO project, the already started process of transformation toward ecologically sound banks got an extra momentum.

This story starts with a brief description of the existing technological regime of waterside banks (Section 6.2.1). Then, I discuss the Project Ecologically Sound Banks (PMO) and the design approach articulated during this project (Section 6.2.2). It will be shown that this approach was in line with integrated water management as discussed in the preceding case study. Section 6.2.3 discusses how the striving for integrated water management enabled the development and adoption of a new design approach to waterside banks. In the final section, I discuss to what degree the new design approach has been put in practice.

6.2.1 The Existing Technological Regime of Waterside Banks and Bank Protections[125]

Traditionally, waterside banks were designed by people with a technical or civil engineering background.[126] These people were employed by the administer of the bank and were also responsible for maintenance. Sometimes, a consulting engineering was hired to carry out a part of the design tasks. Banks constructions were usually realized by, or with the help from, building contractors.
Waterside bank protections were, and are, relatively simple constructions designed in an artisanal way.[127] Until recently, usually existing bank protections that had decayed were reconstructed. Designs were mostly based on the existing situation, experience and simple design rules. Often, standard solutions were used consisting of hard substrates like stone, wood and sheet pilings. Often, such constructions were dimensioned so that one knew, from experience, that the chance of failure was small. This led to 'over-dimensioning' and constructions that were more heavy than strictly necessary from a safety point of view. Another reason for choosing 'heavy' constructions was that this would keep maintenance costs low and make the construction more durable.
Waterside bank protection design was thus characterized by a civil engineering approach with an emphasis on the existing state of the art. Until two or three decades ago, most innovations were related to developments in construction materials and building materiel.[128] More recently, several new constructions have been developed for circumstances in which more extreme requirements are posed.[129] Often such constructions were developed in related technological regimes like those of dikes and coastal barriers. If cost-effective, they were later applied in the technological regime of waterside banks.
The development and application of innovations in waterside bank protections are, as a rule, guided by the functional requirements posed.[130] These requirements are somewhat situation-specific and may differ from waterway to waterway and from bank to bank. To an important extent, it depends on the administrator of the waterside banks which construction is chosen and whether particular innovations are applied.
The development and acceptance of innovations further depend on actors that play a more central role in the technological regime of waterside banks, including the Civil Engineering Center for Research and Regulation or CUR (*Civieltechnisch Centrum Uitvoering Research en Regelgeving* and Rijkswaterstaat.

The CUR coordinates civil engineering research and formulates design rules and norms.[131] In it, the government, business and researchers cooperate. Parties can ask the CUR to initiate research or to formulate (design) rules and norms. If CUR decides to do so, a special committee is established in which representatives from the involved parties take a seat. These involved parties may include the government,

Rijkswaterstaat, engineering firms, building contractors, suppliers of construction materials, Water Boards and research institutes. As a rule, CUR committees act as supervisors while the actual research is contracted out to research institutes, universities or engineering firms. For an important part, this research is paid by the parties involved.[132] On the basis of the outcomes of the research, CUR - *i.e.* the specially established CUR committee - publishes reports, handbooks, guides, recommendations and norms. The latter are usually formulated in cooperation with the NNI, the Netherlands Institute for Normalization.
CUR publications are important design tools and guides for the design of waterside banks. Since all of the major actors in the regime of waterside banks are usually represented in CUR committees, the CUR may authoritatively formulate new design standards and rules and lay the foundation for a new state of the art.

Rijkswaterstaat plays several roles in the regime of waterside banks. It administers the larger Dutch waterways with national (shipping) functions. It carries out and commissions research on waterside bank protections and it acts as regulator. These activities are carried out by different units or divisions within Rijkswaterstaat (*cf.* Figure 6.4).
Dienstkringen are responsible for the day-to-day maintenance of waterways and their waterside banks.[133] They are responsible for, and partly carry out, reconstruction and design activities with respect to waterside banks. Most *dienstkringen* have a technical department responsible for design, construction and technical maintenance work.
Dienstkringen are relatively autonomous units within Rijkswaterstaat. Nevertheless, they depend on other parts of Rijkswaterstaat in several ways. They have to comply

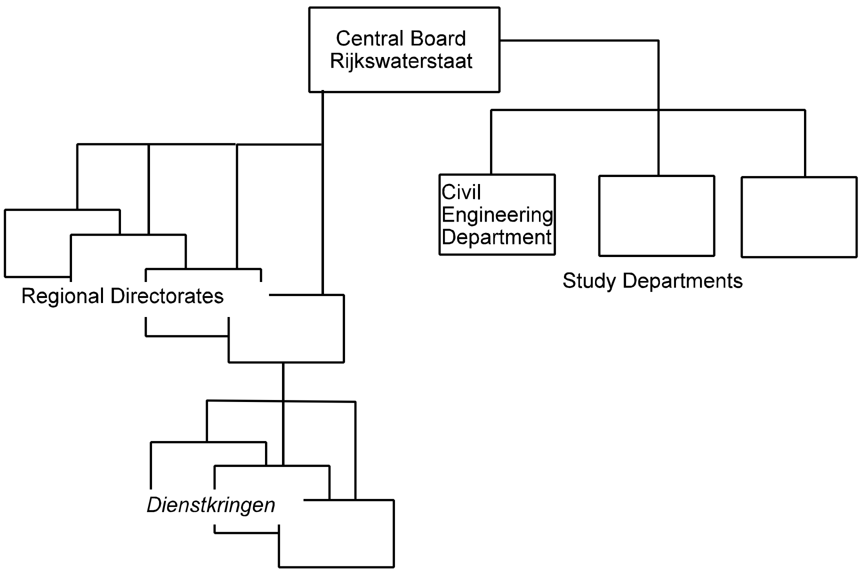


Figure 6.4 *The Rijkswaterstaat Organization*

with the policy of the regional directorates (*Regionale Directies*) of Rijkswaterstaat of which they are part. *Dienstkringen* also depend on the central organs of Rijkswaterstaat for financial and technical assistance. Larger maintenance and (re)construction schemes for banks have to be approved by the central board (*Hoofddirectie*) of Rijkswaterstaat for financial assistance.[134] Rijkswaterstaat centrally formulates, in cooperation with the Ministry of Transport and Communications, several-year plans for the (re)construction of waterside banks.[135] *Dienstkringen* further depend on the Civil Engineering Department (*Dienst Weg- en Waterbouwkunde*) of Rijkswaterstaat for technical advice.[136] The Civil Engineering Department is one of the central study departments (*Specialistische Directies*) of Rijkswaterstaat. It carries out and commissions research on waterside banks.

The activities of *dienstkringen* and the Civil Engineering Department are to some extent guided by missions formulated by the central board of Rijkswaterstaat and the central government, especially the Ministry of Transport and Communications of which Rijkswaterstaat is part. These missions will also affect regulation and subsidy schemes. Consequently, the innovation pattern may be characterized as mission-oriented.

The position of Rijkswaterstaat in the regime of waterside banks is less central than in the regime of coastal barriers. Moreover, the central organs of Rijkswaterstaat and the central government play a less direct role in the design of waterside banks than in the design of coastal barriers. Partly, this is due to the fact that the units within Rijkswaterstaat that commission and partly carry out the design of waterside banks, the *dienstkringen*, are more autonomous than the units that carry out coastal barrier projects, which is usually done by study departments or specially established departments of Rijkswaterstaat. The larger role of the central board of Rijkswaterstaat and the government in coastal barrier projects is also due to the fact that coastal barrier projects only take place seldom, are technologically more complex and far more expensive.

The innovation pattern in the technological regime of waterside banks then is less outspoken mission-oriented than in the regime of coastal barriers. This is even more so for waterways that are not administrated by Rijkswaterstaat. Such waterways are administrated by such actors as Water Boards, provinces, municipalities, private persons and conservationist organizations. Of these actors, I will especially focus on Water Boards.

Water Boards are a special kind of local authorities established to fulfill a set of circumscribed functions in their territory.[137] The election of the members of the administration of a Water Board and its financing, via special taxes, are directly connected to the functions that a Water Board is to fulfill. These functions define a number of interested parties who elect the administration of the Water Board and pay the taxes. Traditionally, many Water Boards had as main functions the protection against (high) water and the regulation of water transport. The interested parties were mainly farmers. As a result, Water Boards traditionally emphasized rapid water transport and the protection of the land.[138]

Although Water Boards are part of the government, they are traditionally relatively autonomous in their policy. Influencing their policy in a direct way is difficult for the central government. As a result, Water Boards are rather autonomous in the execution of particular waterside bank projects. Such projects will only to a small extent derive from missions formulated by the central government or the central organs of Rijkswaterstaat. Therefore, the innovation pattern with respect to banks designed by Water Boards has some user-driven characteristics.

6.2.2 The Project Ecologically Sound Banks of Rijkswaterstaat[139]

The deployment of initiatives with respect to ecologically sound banks reflects the existing technological regime and its innovation pattern. Initiatives started locally, depending on the local possibilities and the existing (ecological) functions of waterways, the actions of local conservationist organizations and the willingness of local administrators to take ecological considerations into account.[140] Local initiatives could be undertaken relatively easily due to the relative autonomy of administrators of waterside banks (including the *dienstkringen* of Rijkswaterstaat) and the fact that waterside bank protections are relatively simple constructions designed in an artisanal way. It was not so difficult to think out and apply constructions that were ecologically more sound, or at least seemed to be so.
Local initiatives, however, hardly amounted to a transformation of the technological regime of waterside bank constructions as a whole. The striving for ecologically sound banks reached the agenda of the entire regime when Rijkswaterstaat started the Project Ecologically Sound Banks or PMO (*Project Milieuvriendelijke Oevers*) in 1985. The goal of the PMO was 'to promote an analytical approach with respect to the construction and maintenance of banks, so that the multifunctional character of the bank is respected. By that, ecological functions and functions relating to the landscape deserve extra attention.'[141] The slogan op the project was: 'Construction of ecologically sound banks: also here cooperation between mesmerized civil engineers and civilized biologists,'[142]
The bureau of the project resided at the Civil Engineering Department of Rijkswaterstaat. It merely consisted of Jan Koolen, a former employee of the RIZA (Netherlands Institute for Integral Fresh Water Management and Waste Water Treatment, a study department of Rijkswaterstaat), now working at the Civil Engineering Department. PMO further consisted of a coordinating committee and four working groups for rivers, canals, lakes and tidal waters.[143] Each of these groups consisted of a different mix of representatives from the various regional directorates and special (study) departments of Rijkswaterstaat. The director of the Civil Engineering Department headed the coordinating committee.[144]
Due to the existing roles of Rijkswaterstaat in the regime of waterside banks, the PMO-bureau could undertake a range of activities with respect to ecologically sound banks. It commissioned several research and experimental projects to acquire relevant knowledge for the design, construction and maintenance of ecologically sound banks. Examples are research projects on the ecological functions and potentials of waterside banks, research projects on the use of vegetation to strengthen banks and research projects on the costs of ecologically sound banks. Most research projects were financed by PMO and carried out by research institutes like the special

study departments of Rijkswaterstaat, the Netherlands Organization for Applied Research TNO, ecological research institutes and the universities.
The PMO-bureau also undertook a range of activities to articulate and make authoritative a new design approach to waterside banks. PMO successfully tried to lay down the striving for ecologically sound banks in relevant policy documents. The CUR was asked to formulate guidelines for the design of ecologically sound waterside banks.[145] The CUR was asked because it was hoped that this would further the acceptance of ecologically sound banks by administrators of waterside banks and by the other actors involved like engineering firms and building contractors.
The various activities by the PMO-bureau, research institutes and the CUR then resulted in the articulation of a new approach to the design of waterside banks and the translation of this approach into more concrete guidelines and heuristics. These were laid down in the *Handbook Ecologically Sound Banks* published by the CUR in 1994 and in several publications of the PMO-bureau.

The new approach to waterside bank design advocated in the PMO and the *Handbook Ecologically Sound Banks* is in line with integrated water management. In this approach, the bank is conceived as a multifunctional object or system. This implies that more stress is placed on ecological design criteria than before:

> *Banks function as protection and, apart from that, have ecological and scenic functions like the creation of chances for survival for plants and animals belonging there. During design and construction of ecologically sound banks, these chances of survival should be treated as criterion, equal to criteria like safety, ease of maintenance, etcetera. This and that should conform with other forms of use, like recreation, agriculture and so on.*[146]

In other words, banks have different functions, which should be respected and hence different design criteria are important. This does, however, not imply that ecological considerations and criteria have to play an important or decisive role in each concrete project. Occasionally, realizing an ecologically sound bank may be impossible due to the other functions of a waterside bank. The term ‘ecologically sound banks’ is mainly chosen for strategic reasons:

> *The term ‘ecologically sound’ is used for the new policy. ‘Multifunctional’ would have been better. The term ‘ecologically sound’ is chosen to stress the contrast with the existing civil engineering view on bank protections.*[147]

The contrast with the existing approach to waterside bank design is not only reflected in the design criteria to be reckoned with. It is also reflected in what is seen as the actual object of designing. While traditionally bank *protections* were designed, now waterside *banks* have to be designed. The waterside bank should be conceived as part of a larger ecosystem. Ecological functions of banks like that of living place (habitat) or migration route (corridor) therefore should be realized in relation to the surrounding land and water.[148]

In the PMO and the *Handbook Ecologically Sound Banks*, a more analytic or systemic way of designing banks is advocated. Design and construction of ecologically sound banks are seen as part of a cyclic process of bank management and maintenance (Figure 6.5). Of the various elements in Figure 6.5, the formulation of a bank management vision and of a (re)construction plan are most important for the design of ecologically sound banks.
The inclusion of the formulation of a bank management vision is itself a major break with the traditional way of designing banks. Traditionally, the goals or functions of a bank (protection) were more or less taken for granted.[149] Not much explicit thought was given to the question which functions had to be fulfilled by the bank. According to the PMO and the *Handbook*, the goals and functions to be fulfilled by the bank had to be formulated in an explicit and systematic way. Since a waterside bank is a multifunctional object, not only civil engineers should be involved in the formulation of a bank management vision:

> *The contribution of all sorts and conditions of experts should be much emphasized in the case of ecologically sound banks: ecologists, civil engineers, experts of the landscape, experts of recreation following, together, a planned approach if the bank is to be reconstructed. The interference of ecologists and other experts with the bank implies a major break with the past. A rather changed position of the civil engineers.*
> *A very new division of roles has been established around the construction of banks.*[150]

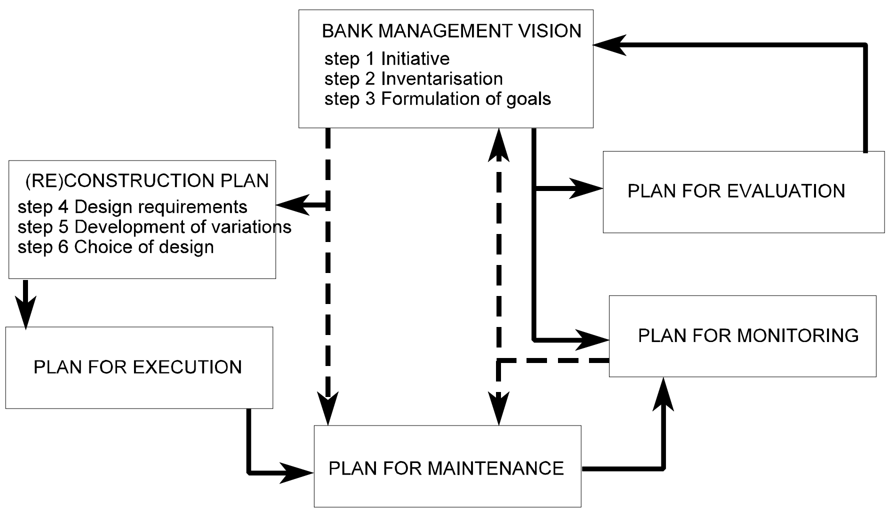


Figure 6.5 *Design Process and Policy Plan for Ecologically Sound Banks (reproduced from CUR Report 168, Natuurvriendelijke Oevers, Gouda: CUR, 1994)*

The exact filling-in of this new division of roles depends on the phase of the design process. An employee of the Department of Civil Engineering of Rijkswaterstaat has described the roles of ecologists and civil engineers in the early stages of the design process as follows:

> *During initiative, there is no clear division of tasks: Everyone can take the initiative: the ecologist who observes that nature in the bank has not enough possibilities to develop, the civil engineer who observes that the bank is eroding too fast, the recreational expert who feels that there are too few facilities for, for example, anglers.*
> *In this phase, the decision is made that something has to be done with the bank.*
>
> *During the making of the inventory, the civil engineers collect information about the existing situation of the protection, the hydraulic loads on the bank and the condition of the soil. The ecologists look at the existing nature in the bank (plant and animal life) and gather information about the potentials of nature, given the local circumstances. In this way, also the other experts get at work.*
> *The result is an objective inventory of the boundary conditions of the bank.*
>
> *The third step is very important, because it implies the indication of what should be done with the waterside bank, the goals are formulated. In the case of ecologically sound banks, the ecologist now takes the initiative. He or she must tell which ecological situation on the bank is possible and desirable, within a particular period of time. We have called this the policy target.*[151]

The proposed roles of civil engineers, ecologists and other experts thus differ somewhat from step to step during the formulation of the bank management vision. The same holds *grosso modo* for the following three steps proposed in the *Handbook*: the formulation of a (re)construction plan. The first step in the formulation of the (re)construction plan is the formulation of the requirements for the design of the bank. According to the *Handbook*, the 'design requirements in the first place concern the requirements of the desired living communities, the desired natural processes, and the desired species ... The design requirements should also sketch a picture of the required strength of the bank. ... Third, the requirements arising from possible additional functions should be known.'[152]
In this phase, each of the involved experts is responsible for formulating specific requirements within the boundaries of the earlier formulated goals and policy target. Potential conflicts among the requirements should be solved by indicating priorities. Such 'priorities are dependent on the specific location and may differ from bank to bank. In general, safety, shipping, water management and ecology will be most important.'[153]

The following step is the development of a number of variations. Now, the civil engineers will take the initiative in translating the formulated goals and requirements into constructions. Nevertheless ecologists (biologists) can play an important role as ‘architects’:

> *During the development of design variations based on the requirements, the composition, expertise and creativity of the design team play an important role. It is important that during this step intensive cooperation takes place between biologists and technicians. The greater the importance of nature the more biologists should act like architects while the technicians should devise the technical solutions.*[154]

After several variations have been formulated in this way, a choice has to be made between them. Again the various experts are to be involved.[155] After the choice for a particular variant is made, the design has to be executed.

The *Handbook* does not present standardized bank constructions. Proponents of ecologically sound banks have emphasized that: ‘*The* ecologically sound bank does not exist.’ In the words of the *Handbook*:

> *Waterside banks differ from location to location, therefore ecologically sound banks are tailor-made. The application, without changes, of solutions that are successful elsewhere, may not only be undesirable but unwise too.*[156]

Nevertheless, the *Handbook* provides many clues for the design of ecologically sound banks in various specific circumstances. It does so by discussing various types of waterside banks. Waterside banks are differentiated with respect to types of water (smaller waters, rivers, canals, fresh lakes, saltish and brakish lakes, saltish tidal waters). Waterside banks along smaller waters are further differentiated in terms of the type of hinterland and the type of waterway.
For each of the various types of waterside banks, a reference ecosystem is described. A reference ecosystem is defined as follows in the *Handbook:*

> *To perceive what is possible in the given waterside bank with respect to nature, it is important to know what nature would have looked like in natural circumstances, given the existing climatological and biogeographical circumstances. This is called the reference ecosystem.*[157]

A reference ecosystem can be reconstructed by an analysis of historical developments, comparison with areas elsewhere and a description of the situation in which nature is left alone.[158] The *Handbook* describes reference ecosystems for various types of waterside banks. In many cases, a waterside bank with a slight slope is presented as reference.
Since the reference ecosystem can be attained seldom in concrete cases, a feasible policy target should be formulated. This target should follow from the defined

reference ecosystem and the (unchangeable) boundary conditions that apply to the given case. Such boundary conditions, for example, may consider shipping. The *Handbook* describes the commonly existing situation and the possibilities to attain ecologically more sound banks for various types of waterside banks. It is up to the administrator of the water to define the policy targets in the concrete case.

Apart from the description of reference ecosystems, the formulation of several design heuristics in the *Handbook* strikes the eye. Recurring design heuristics are 'use the capability of the water system and its characteristic processes to create specific living areas for plants and animals' and 'use materials that do not endanger the environment.'[159]

Finally, the *Handbook* presents (technical) constructions and materials that may be used for ecologically sound banks. Properties of these constructions and materials are listed and tools to calculate the strength of different types of banks are presented. Included are also unprotected banks and the use of natural vegetation as bank protection.

6.2.3 Ecologically Sound Banks and the Striving for Integrated Water Management

The design approach advocated in the *Handbook Ecologically Sound Banks* deviates drastically from the traditional way of designing banks. It implies not simply or merely the application of new bank constructions or the taking into account of ecological criteria, but an almost complete new way of designing banks. Bank designs should derive from a bank management vision that is part of a more encompassing management vision for the waterways in an area. In the formulation of this vision, and in the different phases of the design process, ecologists, biologists and other experts should become closely involved besides the traditionally involved civil engineers.

This new design approach is in line with the striving for integrated water management as discussed in the preceding case study. As such, it followed on several developments in water management that have taken place in the Netherlands since the seventies. In this section, I briefly describe these developments to show how they enabled the striving for ecologically sound banks.

Until the early seventies, (fresh) water management in the Netherlands focused on quantity and safety issues.[160] In this period, the organizations responsible for water management in the Netherlands, like Rijkswaterstaat and the Water Boards, merely employed civil engineers. In the seventies, increasingly attention was paid to the water quality of especially the fresh waters.[161] This was, indirectly, the result of the growing deterioration of the water quality of these waters and growing ecological awareness among the population. In time, attention for water quality shifted from an approach emphasizing standards for single pollutants to an approach taking the complete water ecosystem as starting point. Now, an increasing number of ecologists and biologists came to be employed by Rijkswaterstaat, the Water Boards and other water administrators.[162] These ecologists and biologists have developed tools to assess the ecological quality and functioning of the water (eco)system.[163] They also undertook (local) initiatives with respect to ecologically sound banks.[164]

In the eighties, increasingly the term 'integrated water management' was used to emphasize the integration of quantity and quality issues with respect to fresh water management.[165] Meanwhile, the term was used in reference to the new design approach developing during the *Oosterschelde* project (see Section 6.1.4). In this approach, the water system is taken as point of departure and emphasis is placed on the different functions of the water system. Such an approach offered good opportunities to integrate quantity and quality issues since such issues may be defined as different functions of the water.

Integrated water management became a basis for governmental policy with respect to water management in the eighties (Box 6.4). In 1985, the governmental memorandum *Living with Water* appeared. This memorandum advocated an integrated approach to water management. In 1988/1989, the Third Memorandum on the Water Economy (*Derde Nota Waterhuishouding*) was issued. Now, integrated water management became the official point of departure for water management in the Netherlands.[166] In the Third Memorandum also attention is paid to the striving for ecologically sound banks. According to the memorandum, waterside banks shall be constructed and designed in an ecologically sound way, unless this is impossible for other reasons.

In the late eighties and early nineties, regional directorates of Rijkswaterstaat and Water Boards became obliged to formulate integral policy plans for water management in their area.[167] Water Boards became so due to the Law on the Water Economy or WWH (*Wet op de Waterhuishouding*) that came in force in 1990.[168] Water Boards have to formulate water management plans, which have to be in line with the policy plans of provinces with respect to water management.[169] The water management plans of the Water Boards are authorized by the province, after a round of participation of the population. In the plans of the Regional Directorates of Rijkswaterstaat and Water Boards, integrated water management will often play an important role.

In response to the sketched developments, research institutes and engineering firms increasingly began to pay attention to integrated water management.[170] Many engineering firms have set up divisions for integrated water management and advertized their activities in such terms. Research institutes and engineering firms also have developed knowledge and specific design tools for integrated water management.

The striving for integrated water management has also brought new actors to the fore. Research institutes with ecological expertise playing a marginal or no role in water management became more prominent. Further, a number of ecological consultancies have been set up since the late seventies.[171] In general, the striving for integrated water management has buttressed the growing role of ecologists and biologists in water management.

The sketched developments in water management, and especially the striving for integrated water management, have enabled the striving for ecologically sound banks in several ways.

First, due to the articulation of the integrated water management approach, new knowledge and (design) tools became available. In the PMO, existing approaches and tools were tailored to ecologically sound bank and new knowledge and tools were developed. So, the development of a new design approach for ecologically sound banks was enabled by the fact that the striving for integrated water management had become more articulated over the years.
Second, water administrators became obliged to formulate policy plans for their waterways. This offered possibilities to lift waterside bank design to a higher level, as intended in the *Handbook Ecologically Sound Banks*. Functions of waterside banks could not simply be taken for granted but should be spoken out in policy plans. Even if water administrators choose to neglect ecological functions, the existence of policy plans offers other actors like the central organs of Rijkswaterstaat, provinces and environmental groups the possibility to criticize the policy of water administrators, before the actual design and construction of waterside banks start. Moreover, the general commitment in the sector to integrated water management means that water administrators in their policy plans often at least will pay lip-service to integrated water management and, hence, to ecologically sound banks.
Third, the sketched developments in water management implied that ecological expertise and workforce had become available among the actors in the technological regime. As we have seen, the design approach pleaded for in the *Handbook Ecologically Sound Banks* implied that ecologists and biologists had to be directly involved in the formulation of policy plans and in some phases in the design process of ecologically sound banks. This transformation was enabled by the fact that water administrators like the regional directorates of Rijkswaterstaat and (some) Water Boards had come to employ ecologists and biologists. Ecological expertise also became available at engineering firms. Finally, a number of ecological consultancies had started to offer it services.

6.2.4 Ecologically Sound Banks in Practice

The preceding section suggests that integrated water management has begun to function as a guiding principle in water management. The actors involved indeed increasingly explain, defend and advertise their activities with respect to water management in terms of integrated water management. The integrated water management approach has also been translated into several concrete design tools that can be used in the design of such works as coastal barriers and waterside banks. The new design approach advocated in the *Handbook Ecologically Sound Banks* can in this respect be seen as a specification of the general striving for integrated water management.
However, integrated water management has until now not been completely successful as new guiding principle. The degree to which the actions of the actors involved are guided by the striving for integrated water management in general and ecologically sound banks in particular differs from actor to actor.[172] While the central government and Rijkswaterstaat have committed themselves to the striving for

ecologically sound banks, they have not been completely successful in convincing local water administrators. This is in particular due to the relative autonomy of local water administrators and to the political and juridical status of Water Boards.

Ecologically sound waterside banks have until now only been applied in experimental projects or when special subsidies were available.[173] Reasons for the hesitance of water administrators to choose for ecologically sound waterside banks are uncertainty about the costs, strength and durability of ecologically sound banks, the low rate of replacement (reconstruction) of waterside banks and the difficulties in acquiring extra land for ecologically sound banks.[174] The latter may be required because ecologically sound banks are usually broader than traditional banks. The water administrator may have to buy this extra land. This brings extra costs and requires the cooperation of the owner of the land, often farmers. Expropriation of land on the basis of ecological arguments is not (yet) possible.[175]
Apart from the named reasons not to apply ecologically sound banks, local water administrators meet several practical problems if they want to design ecologically sound banks. A general problem for the striving for ecologically sound banks is that the people directly involved in bank design and the formulation of management plans often still have a rather technical-pragmatic attitude.[176] Ecologically sound banks are sometimes perceived as just another type of standard construction. Consequently, new constructions and construction materials are sometimes ordered that are being advertised as ecologically sound by building contractors and suppliers of materials, but that are not ecologically optimal in the specific circumstances. Another consequence may be that ecologists and biologists are called in too late, for example, when the orders for new construction materials have already been placed. A related problem is that the formulation of integrated policy plans for banks has until now not been quite satisfactory.[177] Often, the formulation of plans and the construction of ecologically sound banks happens from a constructive-technical point of view.[178] Ecological considerations come next. Ecological knowledge is often systematically applied. Sometimes, alternatives with ecological potentials are overlooked. Knowledge of ecological potentials, and their translation into design criteria, is also sometimes lacking.[179] This is related to the fact that nature in an ecologically sound bank cannot be designed.[180] Only boundaries conditions can be created. It may take years of monitoring and evaluation to gain insight into the relation between particular boundary conditions in an ecologically sound bank and the development of nature.

The preceding explains why local administrators have been hesitant in commissioning and designing ecologically sound banks. A main reason why they could resist the pressure from other actors, like Rijkswaterstaat and the central government, to apply ecologically sound banks is their relative autonomy (*cf.* Section 6.2.1). Especially Water Boards can resist the striving for ecologically sound banks because they are more autonomous than the *dienstkringen* of Rijkswaterstaat. Usually, Water Boards have been more hesitant with respect to ecologically sound banks than the *dienstkringen* of Rijkswaterstaat.[181] Apart from the autonomy of Water Boards, this finds its background in the fact that it is more difficult for Water

Boards than for *dienstkringen* to acquire additional finances.[182] *Dienstkringen* can rely on (special) funds of Rijkswaterstaat. Water Boards have to levy taxes and they can only do so for the primary functions for which they have been established. According to the Water Boards, the protection of ecological values is not a primary function for which taxes can be levied. It is a so-called 'related interest.' As the Union of Water Boards argued in its reaction to the Third Memorandum on the Water Economy:

> *It should be realized that Water Boards have no account to charge the inhabitants for these - in themselves valuable measures [for ecologically sound banks, IvdP]. This is the case because such measures do not belong to the tasks laid down in the regulations of the Water Boards. This does not mean that Water Boards have no (financial) responsibilities at all in this respect. It is conceivable that sometimes related interests can be achieved against no or few extra costs. This does, however, not change the point, that derives from principles inherent to the institution of the Water Board, that Water Boards are primarily responsible for 'task interests.' [. . .]*
> *It seems that no general rules can be formulated for the protection of related interests by a Water Board. This implies that the Water Boards from case to case have to consider whether and if so till what extent a contribution can be provided.*[183]

In other words, it is up to individual Water Boards to decide autonomously whether they want to design and construct ecologically sound banks. According to the Union of Water Boards, Water Boards may be expected to choose for ecologically sound banks if there are little extra costs.[184] Otherwise, it will depend on the possibilities for subsidies. For ecologically sound banks with a great width, the costs should be borne by other instances than Water Boards, according to the Union of Water Boards.[185]

The reaction of the Union of Water Boards may be interpreted as an attempt to retain the autonomy of Water Boards. The central government tried to bring to heel Water Boards by the earlier mentioned Law on the Water Economy (WWH). This law obliged Water Boards to formulate policy plans in accordance with the policy of the central government and the striving for integrated water management.

While the reaction of Union of Water Boards may have had strategic reasons, it also reveals a real constraint for Water Boards to choose for ecologically sound banks. The existing political and juridical status of Water Boards is based on the assumption that Water Boards have to fulfill a limited number of functions with respect to water management, while the striving for ecologically sound banks and for integrated water management is based on a multiplicity of functions to be fulfilled, including ecological functions. This problem applies to the striving for integrated water management in general. It is related to the fact that the existing political and financing structure with respect to water management is not quite apt for the striving for integrated water management.[186] Task divisions between different authorities and water administrators are often not quite clear and there exist financial and juridical (expropriation of land) barriers for the implementation of the striving for integrated water management.[187]

The overall picture with respect to the resulting transformations in the technological regime of waterside banks then is quite comparable to the regime of coastal barriers. To an important extent, the striving for ecologically sound banks and for integrated water management have become part of the mission of the regime. The striving has been accepted by important actors in the technological regime, translated into more concrete design approaches, criteria and tools that are put in practice. Meanwhile, the application of ecologically sound banks is constrained by existing institutional structures, interests, values and the autonomy of local water administrators.

6.3 Discussion and Conclusion

The processes of transformation described in this chapter set off when outsiders like critical scientists and environmental groups made manifest the aggression of the existing technological regimes. They revealed and protested against negative ecological effects of coastal barriers and waterside banks. In both cases this led to a reformulation of the mission of the existing technological regime. This route for the feedback of secondary effects can be seen as a combination of the routes of user pressure and regulation. These routes addressed the designer/producers of a technology respectively via regulators (regulation) or via users (users pressure). In regimes with a mission-oriented innovation pattern, the roles of regulator and user/principal are played by one actor: ‘the government as client.’ So, transformation of a technological regime via a reformulation of the mission may be seen as a combination of the routes of regulation and user pressure. This combination is unique to regimes with a mission-oriented innovation pattern.

In both cases, the reformulation of the mission of the existing technological regime resulted in a demand upon ecologists and biologists. These initial outsiders became involved in the formulation and operationalization of design criteria and the development of new design tools because they possessed knowledge that was not yet available in the existing regime. Eventually, both processes of transformation resulted in the articulation of a new design approach. These approaches were in line with the new guiding principle ‘integrated water management’ formulated in the eighties with respect to water management. As we have seen, integrated water management has partly been accepted as a new guiding principle in water management and relevant technological regimes like that of coastal barriers and waterside banks.

The partial acceptance of integrated water management as new guiding principle further enabled the incorporation of ecologists and biologists via a demand. Integrated water management, and the more specific design approaches in both technological regimes that derived from it, allocated new roles to already involved professionals and to initially outsider professionals like ecologists, biologists, landscape gardeners and recreational experts. As far as integrated water management was accepted as new guiding principle by all actors in the technological regimes, it made a role for new professional experts legitimate and even ‘natural.’

In the case of the *Oosterschelde*, the reformulation of the mission was enabled by the fact that missions for coastal projects have to be approved by parliament. This made it possible to reformulate the mission via democratic decision-making. Meanwhile, the reformulation of the mission was constrained by the fact that Rijkswaterstaat combined the roles of principal, (co)designer and researcher in the existing technological regime. Rijkswaterstaat had a near monopoly on the carrying out and commissioning of R&D and design activities. For some time, it could block the development of technical alternatives and the reopening of the debate on the mission of the *Oosterschelde* project.

The attitude of Rijkswaterstaat began to change after 1972. This was not so much due to a reformulation of the mission of the *Oosterschelde* project by the central government, that came only later, but to the fact that protesters had successfully organized public pressure on Rijkswaterstaat. This public pressure was the result of the delegitimation of the closure of the *Oosterschelde*. Delegitimation was achieved by linking negative (secondary) effects of the *Oosterschelde* closure with the neglect of generally held values. This linking was both a more or less conscious strategy of protesters and the unintended outcome of growing media attention and the politicizing of the debate. As a result, an increasing part of the public came to see the closure of the *Oosterschelde* as undesirable.

After 1972, Rijkswaterstaat increasingly began to feel a need to regain public legitimation and trust. Therefore, Rijkswaterstaat did not carry out the first feasibility study on the Klaasesz solution, but commissioned the study to the building contractors united in DOS. Later, Rijkswaterstaat itself proposed new technical alternatives. By then, it was becoming increasingly clear that the central government might reformulate the mission of the *Oosterschelde* project. The government clearly aimed at a decision in which ecological criteria were to play a role besides criteria of safety.

The growing emphasis on ecological criteria led to a demand upon ecologists and biologists in the storm surge barrier project. Especially after the definite decision of parliament to build a storm surge barrier, ecologists quickly assumed an important role in the *Oosterschelde* project. This role was enabled by the reformulation of the mission of the *Oosterschelde* project. This new mission was rather effectively implemented in the technological regime of coastal barriers due to the important position of Rijkswaterstaat in this regime.

The larger role of ecologists and biologists was also enabled by the fact that for many civil engineers, like Engel, the *Oosterschelde* became the key-project to prove that Rijkswaterstaat was not an irresponsible organization that neglected ecological considerations. Further, the new role of ecologists was abetted by the cooperative, practice-oriented attitude of the Environmental Division. This organization was a vehicle for the closer involvement of ecologists in two senses. First, the Division employed ecologists and biologists. Second, it commissioned ecological research and functioned as a kind of ‘intermediary’ for research outcomes to other parts of the Delta Department and Rijkswaterstaat.[188]

After the articulation and partly acceptance of integrated water management as new guiding principle, the new role of ecologists and biologists increasingly became more ‘natural.’ No longer, they had to prove their necessity with respect to individual projects. Instead, they could refer to integrated water management as new guiding principle.

In the case of waterside banks, initiatives for ecologically sound banks started locally and before the mission of the entire regime was reformulated. This was possible because local water administrators were relatively autonomous in formulating missions for local projects. The development of these local initiatives did, however, not amount to a transformation of the entire technological regime. The initiatives were emphatically local in nature. They functioned as a kind of protected spaces for the development and monitoring of ecologically sound banks.
The issue ‘ecologically sound banks’ reached the agenda of the entire technological regime when Rijkswaterstaat and the CUR began to employ initiatives. Both these actors were active at the global level of the technological regime and played an important role in the formulation of a new mission. Both organizations were an important forum for technical agenda building, the process in which the intended new mission was translated into more concrete design approaches, criteria, heuristics and technical features.
In the case of waterside banks, the implementation of the new mission was enabled by the fact that integrated water management had already been partly accepted as new guiding principle in water management. Compared with the *Oosterschelde* case, the implementation of the new mission was constrained by the fact that local water administrators were relatively autonomous in formulating missions for specific local projects. The same autonomy of local water administrators that enabled earlier initiatives with respect to ecologically sound banks now constrained the effective implementation of a new mission for the entire regime. In response to this constraint, the central government has undertaken attempts to encourage that local missions became more in line with integrated water management, so making the innovation pattern more truly mission-oriented.

Comparing the cases reveals a difference in the degree to which missions actors, like Rijkswaterstaat, could effectively redefine the mission of the existing technological regimes. This difference is related to initial differences between both technological regimes. In the coastal barrier regime, missions for specific projects directly derived from or coincided with missions for the entire regime. In the regime of waterside banks, missions for specific projects only indirectly derived from centrally formulated missions. Local water administrators were relatively autonomous in formulating missions for specific projects. This created opportunities for local initiatives with respect to ecologically sound banks. Meanwhile, it made it more difficult to effectively implement the striving for ecologically sound banks through a reformulation of the mission of the regime as a whole.
The cases then show that the effectiveness with which central mission actors, like Rijkswaterstaat and the central government, can effectively reformulate the mission of an entire technological regime partly depends on the existence of local principals and the autonomy they have. In the coastal barrier regime, the central government and Rijkswaterstaat formulated the mission for important costal barrier projects. The (hierarchical) distance between the central government, the central organs of

Rijkswaterstaat and the Delta Department was relatively small. In the waterside banks regime, *dienstkringen* of Rijkswaterstaat and Water Boards formulated missions for individual projects. They were rather autonomous in doing so. The innovation pattern had some user-driven characteristics in the sense that designs and innovations derived from functional requirements of local water administrators. These functional requirements could be formulated somewhat independent from overarching missions formulated by the central government and the central organs of Rijkswaterstaat.

Above, we have encountered several ways in which the mission-oriented innovation pattern enabled and constrained the studied processes of transformation. To put in context these findings, making a comparison with the user-driven innovation pattern discussed in the preceding chapter is useful. In both innovation patterns, innovations start with an articulation of new functions by users or principals. Where in a user-driven innovation pattern, new functions are expressed as the functional requirements of users, in a mission-oriented innovation pattern they derive from missions formulated by the central government or governmental agencies. Such governmental agencies either centrally formulate missions for specific projects or more encompassing missions that guide the formulation of missions for specific projects, as in the waterside banks regime.

In the preceding chapter we observed that the user-driven innovation pattern is particularly constraining for processes of transformation, because there is little room to develop technical alternatives independent from functional requirements of users. Something similar applies to the mission-oriented innovation pattern. Here, developing technical alternatives independent from (new) missions formulated by the mission actors is particularly hard. This is especially the case if a small number of actors control the formulation of missions, as in the costal barrier regime. Here, it was particularly hard to develop and get accepted technical alternatives independent from Rijkswaterstaat. In the waterside banks case, developing technical alternatives independent from the central missions actors was more easy because the regime had some user-driven characteristics. Local water administrators had some room to undertake initiatives with respect to ecologically sound banks. This resulted in the creation of protected spaces for alternative banks constructions in a way that is similar to how market niches for alternative eggs amounted to niches for the development of alternative systems (Chapter 5).

There are two important respects in which the opportunities and constraints inherent in the mission-oriented innovation pattern differ from the user-driven innovation pattern discussed in the preceding chapter. One is that missions are usually (re)formulated via bureaucratic procedures and political decision-making, while functional requirements are (re)formulated via the market and different ‘consumption junctions.’[189] Among other things, this means that in a mission-oriented innovation pattern, it is a limited number of actors that formulate the mission of the regime, while a user-driven innovation pattern is usually characterized by a variety of users. This limited number of actors may be able to block the reformulation of the mission of the regime, but once a new mission is accepted, it can relatively effectively be implemented. In fact, the difference between the user-driven and mission-oriented innovation pattern is gradual. The regime of waterside banks had some user-driven characteristics, enabling local initiatives, but constraining the reformulation of the mission of the entire regime. The regime of sewage treatment plants, discussed in Chapter 5, had some mission-oriented characteristics as effluent requirements for individual plants (partly) derived from centrally formulated missions with respect to water pollution.

The second important difference is that mission actors, in contrast to users, are active at the global level of a technological regime and so have an eye for long-term developments and the long-term interests and viability of the technological regime as a whole. Mission actors will therefore more easily demand and undertake the proactive development of technical alternatives.

Notes to Chapter 6

1 quoted in K. v.d. Maas, 'Oosterschelde: van conflict tot compromis,' *Driemaandelijkse Bericht Deltawerken*, (1978)83, 127-140. Quote from page 129, my translation.

2 Parts of this case description were earlier published in I. van de Poel & C. Disco, 'Influencing Technology; Design Worlds and Their Legitimacy,' in J. Perrin & D. Vinck (eds.), *the Role of Design in the Shaping of Technology* (Proceedings from the COST A3 and COST A4 workshop Lyon, France, 3 and 4 February 1995) (Luxembourg: Office for Official Publications of the European Communities, 1996), 93-130.

3 On initiatives to protect the south-west of the Netherlands before the occurrence of the storm flood disaster see, for example, E. de Boer, 'Zestig jaar deltawerken; Dordrecht als opening en sluitpost,' in M.L. ten Horn-van Nispen, H. Lintsen & A.J. Veenendaal (eds.), *Wonderen der techniek; Nederlandse ingenieurs en hun kunstwerken 200 jaar civiele techniek* (Stichting Historie der Techniek) (Zutphen: Walburg, 1994), 197-210; H.A. Ferguson, *Delta-visie; Een terugblik op 40 jaar natte waterbouw in Zuidwest-Nederland* (Den Haag: Rijkswaterstaat, 1988), 54-55; H. Haan & I. Haagsma, *De Deltawerken; Techniek, politiek, achtergronden* (Delft: Waltman, 1984), 9-29 and J. van Veen, *Dredge, Drain, Reclaim. The Art of a Nation* (The Hague: Martinus Nijhoff, 1962).

4 De Boer, *Op. cit.*, 198.

5 *Ibid.*, 209.

6 *Ibid.*.

7 De Boer, *Op. cit.*, 201. *Cf.* also Van Veen, *Op. cit.*.

8 Van Veen, *Op. cit.*, 173-174.

9 On the history and the formulation of the Delta Plan see for example R. Antonisse, *De kroon op het Deltaplan* (Amsterdam/Brussel: Elsevier, 1985); W. Bijker & E. Aibar, 'Dutch, Dikes and Democracy; an Argument against Democratic, Flexible, Good and Bad Technologies,' *Technology & Democracy; The Use and Impact of Technology Assessment in Europe, the 3rd European Congress on Technology Assessment, Copenhagen, 4-7 November 1992*, 538-557; E.K. Duursma, H. Engel & Th.J.M. Martens, *De Nederlandse Delta; Een compromis tussen milieu en techniek in de strijd tegen het water* (2e gewijzigde druk, maart 1983) (Koninklijke Nederlandse Academie van Wetenschappen, 1982); A.F. Leemans & K. Geerts, *Doorbraak in het Oosterscheldebeleid* (Muiderberg: Dick Coutinho, 1983); D.F. Westerheijden, *Schuiven in de Oosterschelde; Besluitvorming rond de Oosterschelde 1973-1976* (Enschede: Universiteit Twente, 1988), Proefschrift; Ferguson, *Op. cit.*; De Haan & Haagsma, *Op. cit.*; *Driemaandelijks Bericht Deltawerken*, (1962)19, 3-11.

10 Duursma *et al.*, *Op. cit.*, 84.

11 Tj. de Haan, 'De betekenis van het Deltaplan voor de beveiliging van Nederland tegen het water,' *Driemaandelijks Bericht Deltawerken*, (1988)123/124, 677-694.

12 Leemans & Geerts, *Op. cit.*, 49-53.

13The Delta law was accepted by parliament in 1957. In 1960, the complete report of the Delta committee was published.

14 D.M. Ligtermoet & H. de Visch Eybergen, *Uitvoering en uitbesteding; Ontwikkelingen in de organisatie van waterbouwkundige werken bij Rijkswaterstaat* (Den Haag: Rijkswaterstaat, 1990). For more details see Appendix 3.

15 For more details, see Appendix 3.

16 Leemans & Geerts, *Op. cit.*, 49; De Boer, *Op. cit.*, 204.

17 Leemans & Geerts, *Op. cit.*, 52-53.

18 This section is mainly based on Antonisse, *Op. cit.*; De Haan & Haagsma, *Op. cit.*; Leemans & Geerts, *Op. cit.*; Westerheijden, *Op. cit.* and K. v.d. Maas, 'Oosterschelde: van conflict tot compromis,' *Driemaandelijkse Bericht Deltawerken*, (1978)83, 127-140.

19 Before that time, already critique could be heard. In 1962, the *Waterkampioen* (Water Champion) devoted a special issue to the *Oosterschelde*. One of the articles stated: 'The closure of the Oosterschelde? I scarcely dare to write it down, but I really hope that it will never take place' (cited in Antonisse, *Op. cit.*, 95, my translation). In 1965 a critical article in the daily newspaper *NRC-Handelsblad* about the closure of the *Oosterschelde* led to questions in parliament (Westerheijden, *Op. cit.,* 117).

20 *Driemaandelijks Bericht Deltawerken*, (1978)83, 127.

21 De Haan & Haagsma, *Op. cit.*, 65; Westerheijden, *Op. cit.*, 118.

22 These groups jointly erected in the beginning of the seventies the *Samenwerking OosterSchelde (SOS)* (Cooperation Oosterschelde). SOS included: Actiegroep Oosterschelde Open, Algemeen Hengelaarsverbond, Koninklijk Nederlands Watersportverbond, Natuurbehoud is Zelfbehoud, Nederlandse Onderwatersportbond, Milieufederatie Brabant, Zeeuws Coördinatieorgaan voor Natuur-, Landschaps- en Milieubescherming, Studiegroep Oosterschelde, Vereniging Milieudefensie, Vereniging Milieu en Leefbaarheid West-Brabant, Vereniging Milieuhygenië Zeeland, Vereniging tot behoud van de Waddenzee, Vereniging van de Mosselhandel, Vereniging van Oesterkwekers en -exporteurs en de Vereniging Zeeuwse Visserijbelangen (Antonisse, *Op. cit.*).

23These were *Arjos* (the youth organization of one of the Christian democratic parties) and the *Wiardi Beckman Stichting* (the scientific bureau of the socialist party). See Leemans & Geerts, *Op. cit.*, 84.

24 *Ibid.*.

25 *Driemaandelijks Bericht Deltawerken*, (1978)83, 130-131; Antonisse, *Op. cit.*.

26 Leemans & Geerts, *Op. cit.*, 85 and 136-137.

27 The *Studiegroep Oosterschelde* (Study Group Oosterschelde) for example conceived safety as the prime goal but denied that closure was the only means to reach this goal (Leemans & Geerts, *Op. cit.*, 54-55).

28 M.C. in 't Anker (ed.), *Zeeuws Meer?: Eindrapport van de Stedebouwkundige Studiegroep "Zeeuws Meer?", betreffende de afsluiting van de Oosterschelde; Mogelijkheden van een stormvloedkering, compartimentering en milieu.*

29 Leemans & Geerts, *Op. cit.*, 150.

30 *Driemaandelijks Bericht Deltawerken*, (1978)83, 130.

31 Rijkswaterstaat, *Het Deltaplan in het licht van de laatste ontwikkelingen* ('s-Gravenhage: Rijkswaterstaat, 1972).

32 Westerheijden, *Op. cit.*, 125-136.

33 The committee consisted of Klaasesz (chairman); the environmental expert prof. dr. P.G. Fohr (Agricultural University Wageningen); the hydraulic engineer prof. ir. J.L. Klein (retired head of the *Provinciale Waterstaat Zuid-Holland* (Provincial Department for maintenance of dikes, roads, bridges and canals in Zuid-Holland)); the fisheries expert prof. dr. P. Korringa (director *Rijksinstituut voor Visserij-onderzoek* (Netherlands Institute for Fisheries Research)); the biologist prof. dr. D.J. Kuenen (director *Rijksinstituut voor Natuurbeheer* (Netherlands Institute for Nature Management)); the planner ir. F.H. van der Linde van Sprankhuizen

(*Provinciale Planologische Dienst Gelderland* (Provincial Planning Department Gelderland) and chairman of the ANWB (a tourist organization)) and the economist prof. dr. P. de Wolff (University of Amsterdam). Secretary was ir. G. Terluin (retired from the *Provinciale Waterstaat Zuid-Holland* (Provincial Department for maintenance of dikes, roads, bridges and canals in Zuid-Holland)).

34 Leemans & Geerts, *Op. cit.*, 110-117.

35 *Ibid.*, 148-150.

36 Commissie Oosterschelde, *Rapport uitgebracht door de Commissie Oosterschelde ingesteld bij de beschikking van de Minister van Verkeer en Waterstaat van 15 augustus 1973* (Den Haag: Staatsuitgeverij, 1974); Westerheijden, *Op. cit.*, 137-155. In the Klaasesz Report five options were presented. The Klaasesz Committee spoke out a preference for a barrier of blocks, later to be replaced by a storm surge barrier (semi-permeable barrier).

37 *Cf. Driemaandelijks Bericht Deltawerken*, (1978)83, 137.

38 Westerheijden, *Op. cit.*, 160-164.

39 *Ibid.*, 163-164.

40 *Ibid.*.

41 Leemans & Geerts, *Op. cit.*, 148.

42 Typical is that Rijkswaterstaat in its own journal on the Delta Works did not pay any attention to the public protests against the closure of the *Oosterschelde* until 1978.

43 Leemans & Geerts, *Op. cit.*, 153. *Cf.* Westerheijden, *Op. cit.*, 160-190.

44 At one moment, Ferguson, the head of the Delta Department, ordered to make some estimates about costs and time scales of the storm surge barrier more pessimistic (Westerheijden, *Op. cit.*, 172-173). Years later, even these estimates turned out to be (far) too optimistic, but this does not change the intention of Ferguson to present the storm surge barrier as less feasible than some people in the Delta Department actually thought it was.

45 Westerheijden, *Op. cit.*, 174-188; Leemans & Geerts, *Op. cit.*, 88-89.

46 The remainder of this section is mainly based on Westerheijden, *Op. cit.*, 197-235.

47 In 1974, Engel was not yet the head of the Delta Department, but he was seen as successor of Ferguson, who was at that moment heading the department. Moreover, Ferguson delegated all aspects of the *Oosterschelde* issue to Engel. Therefore, with respect to the *Oosterschelde*, Engel de facto was the head of the Delta Department. In 1976, Engel officially became the head of the Delta Department.

48 Westerheijden, *Op. cit.*, 197-235.

49 Rijkswaterstaat, *Eindrapport stormvloedkering Oosterschelde* (Den Haag: Rijkswaterstaat, 1976).

50 Rijkswaterstaat, *Analyse Oosterschelde alternatieven* (Den Haag: Rijkswaterstaat, 1976).

51 Preparations for this White Memorandum were made by the Environmental Division of the Delta Department. Initially this Division was not allowed by Engel to consider an open *Oosterschelde* as a serious alternative. This option was later added (Interview Saeijs, 6 February 1995).

52 This box is based on M. Pastoors, 'The Oosterschelde Revisited; Evaluation of Ecological Modeling in the POLANO-project (Policy Analysis of the Oosterschelde) 1974-1977,' (1992) Doctoral thesis in Theoretical Biology, University of Amsterdam, Department of Science Dynamics; B.F. Goeller, A.F. Abrahamse, J.H. Bigelow, *et al.*, *Protecting an Estuary from Floods - Policy Analysis of the Oosterschelde, Vol. 1, Summary report* (Santa Monica: Rand Corporation, 1977). The quotes come from page 89 of the latter report.

53 Westerheijden, *Op. cit.*, 223.

54 Engel was convinced that he could not find the required expertise for this study at Rijkswaterstaat or elsewhere in the Netherlands. This was probably the reason why the Environmental Division of the Delta Department did not acquire a central role in the execution of the policy analysis, despite the fact that this division had set up together with Delft Hydraulics and some universities the Ecological Modeling (EMO) group. One reason why the EMO group was not asked is that it was working on a time-scale much longer than the time that was

available between late 1974 and early 1976. Moreover, members of the group had been skeptical about the possibility of using models to predict ecological developments (Pastoors, *Op. cit.*, 7-8).

55 Westerheijden, *Op. cit.*, 222-227; Interview Engel, 3 October 1995; Interview Goemans, 12 October 1995.

56 The minister was very hesitant, especially when Rand took the initiative to consider also the open case besides the storm surge and the closed barrier. The minister felt that if it became known that the open case was also been investigated by Rijkswaterstaat the reached political compromise might be jeopardized. Therefore, the open case was investigated without official knowledge of the minister, and the minister also answered in that sense to questions of parliament about the incorporation of the open case in the investigations (see Westerheijden, *Op. cit.*).

57 Westerheijden, *Op. cit.*, 222-227; Interview Engel, 3 October 1995; Interview Goemans, 12 October 1995.

58 Initially, the results of the analysis of the open case were to be treated in a separate report on heightening the dikes, but finally it was decided to incorporate also this alternative in the White Memorandum (*Ibid.*).

59 The 'reductor' solution implied laying a kind of sill at the bottom of the *Oosterschelde* mouth. This sill would reduce the tide and so enhance the safety of the *Oosterschelde* area.

60 Westerheijden, *Op. cit.*, 253-266.

61 *Ibid.*; Rijkswaterstaat, *Ontwerpnota stormvloedkering Oosterschelde* (Den Haag: Ministerie van Verkeer en Waterstaat en Rijkswaterstaat, 1991).

62 See also the description of the existing technological regime in Appendix 3.

63 There were no ecologists among the Rand people who carried out the POLANO study. Nevertheless, some Rand researchers had a background in biology. Moreover, Dutch ecologists and biologists were involved in the POLONA study and the writing of the White Memorandum. In general, these ecologists seemed to have disapproved of the use of the General Ecomodel and the way the future state of the Oosterschelde ecosystem was predicted. The Rand approach also was hardly followed in Dutch ecological modeling (Pastoors, *Op. cit.*).

64 On the establishment of the Environmental Division at the Delta Department, see Ferguson, *Op. cit.*, 71-72; Interview Saeijs, 6 February 1995; *Driemaandelijks Bericht Deltawerken*, (1971)55, 219-226; *Driemaandelijks Bericht Deltawerken*, (1972)59, 444-447.

65 The establishment of the Environmental Division in 1971 was *not* the result of the growing public protests against closure. It merely started as a personal initiative of the head of the Delta Department, Ferguson. Although Ferguson's idea did not meet applause at Rijkswaterstaat, he succeeded in establishing the division.

66 *Driemaandelijks Bericht Deltawerken*, (1981)95, 287-294.

67 Interview Saeijs, 6 February 1995.

68 *Driemaandelijks Bericht Deltawerken*, (1981)95, 290, my translation. In this article, this strategy is related to the need to achieve good solutions that are acceptable to outsiders: 'mutual trust remains a necessary precondition to achieve good solutions, which are also acceptable to outsiders. To achieve this, the Environmental Department has always meant to present itself not primarily as an interest group, but as an agency that provides objective knowledge about the environment' (290, my translation).

69 Interview Saeijs, 6 February 1995; H.L.F. Saeijs, *Changing Estuaries; A Review and New Strategy for Management and Design in Coastal Engineering* (The Hague: Government Publishing Office, 1982).

70 *Cf. Driemaandelijks Bericht Deltawerken*, (1976)75, 228.

71 Interview Saeijs, 6 February 1995.

72 *Ibid.*.

73 Goeller *et al.*, *Op. cit.*; Leemans & Geerts, *Op. cit.*, 93-95 and 152-161; Westerheijden, *Op. cit.*, 245-249 and 255; Rijkswaterstaat, *Eindrapport stormvloedkering Oosterschelde* (Den Haag: Rijkswaterstaat, 1976); Rijkswaterstaat, *Analyse Oosterschelde alternatieven* (Den

Haag: Rijkswaterstaat, 1976); Rijkswaterstaat, *Ontwerpnota stormvloedkering Oosterschelde* (Den Haag: Ministerie van Verkeer en Waterstaat en Rijkswaterstaat, 1991), Boek 1, Deelnota 1, 48-53; *Driemaandelijks Bericht Deltawerken*, (1976)76, 324-333.

74 An aperture of 11,500 square meters corresponded with a tidal volume of 2.3 meters. Before closure the vertical tide was an estimated 3.5 meters. In its 1974 report, the Klaasesz committee has supposed that a minimal vertical tide of 1.8 meters at *Yerseke* was required for ecological reasons. Later in 1974, an interdepartmental group recommended a vertical tide of 2.3 meters. Until 1976, this 2.3 meters was interpreted as minimum requirement by both Rijkswaterstaat and the government.

75 It should be noted, however, that the final Rand Report did not appear before December 1977.

76 Goeller *et al.*, *Op. cit.*, 89.

77 *Ibid.*.

78 The White Report did not discuss the issue of the magnitude of the aperture of the storm surge barrier at all.

79 Rijkswaterstaat, *Eindrapport stormvloedkering Oosterschelde* (Den Haag: Rijkswaterstaat, 1976), 7-8, my translation.

80 *Cf.* interview Saeijs, 6 February 1995.

81 *Driemaandelijks Bericht Deltawerken*, (1980)92, 103-108; (1981)95, 236-239; (1981)95, 262-27 and (1982)100, 526-531; Rijkswaterstaat, *Op. cit*; Saeijs, *Op. cit.*, 281-320; C.J. van Westen & C.J. Colijn, 'Policy Planning in the Oosterschelde Estuary,' in P.H. Nienhuis & A.C. Smaal (eds.), *The Oosterschelde Estuary (The Netherlands): A Case-Study of a Changing Ecosystem* (Reprinted from Hydrobiologica, vol. 282/283 (1994)) (Dordrecht etc.: Kluwer Academic Publishers, 1994), 563-574; Interview Saeijs, 6 February 1995.

82 *Driemaandelijks Bericht Deltawerken*, (1981)95, 240-247 and (1987)122, 607-612; Antonisse, *Op. cit.*, 176-189; De Haan & Haagsma, *Op. cit.,* 110-119; P.H. Nienhuis & A.C. Smaal, 'The Oosterschelde Estuary, a Case-study of a Changing Ecosystem; An Introduction,' in P.H. Nienhuis & A.C. Smaal (eds.), *The Oosterschelde Estuary (The Netherlands): A Case-Study of a Changing Ecosystem* (Reprinted from Hydrobiologia, vol. 282/283 (1994)) (Dordrecht etc.: Kluwer Academic Publishers, 1994), 1-14; Rijkswaterstaat, *Ontwerpnota stormvloedkering Oosterschelde* (Den Haag: Ministerie van Verkeer en Waterstaat en Rijkswaterstaat, 1991), Boek 1 Deelnota 1, 38-48; Van Westen & Colijn, *Op. cit.;* Interview Saeijs, 6 February 1995.

83 The negative ecological consequences were reinforced by the fact that the partition dams would be ready about a year later than the storm surge barrier. In this period, a larger reduction in the vertical tide was to be expected than the storm surge barrier was designed for. On the other hand, it was estimated - around 1985 - that the mean vertical tide of Yerseke would be about 3 meters instead of the 2.7 meters the storm surge barrier was initially designed for. This offered a larger scope for planning the final closure of the partition dams after the closure of the storm surge barrier and for closing gates for constructional reasons, while ensuring that no irreversible ecological harm was caused.

84 *Driemaandelijks Bericht Deltawerken*, (1983)105, 267-273; Nienhuis & Smaal, *Op. cit.*; P.H. Nienhuis, A.C. Smaal & M. Knoester, 'The Oosterschelde Estuary: an Evaluation of Changes at the Ecosystem Level Induced by Civil-engineering Works,' in P.H. Nienhuis & A.C. Smaal (eds.), *The Oosterschelde Estuary (The Netherlands): A Case-Study of a Changing Ecosystem* (Reprinted from Hydrobiologia, vol. 282/283 (1994)) (Dordrecht etc.: Kluwer Academic Publishers, 1994), 575-592; A.C. Smaal & P.H. Nienhuis, 'The Eastern Scheldt (The Netherlands), from an Estuary to a Tidal Bay; A Review of Responses at the Ecosystem Level,' *Netherlands Journal of Sea Research*, (1992)30, 161-173; Van Westen & Colijn, *Op. cit.;* Interview Nienhuis, 20 February 1995; *NRC-Handelsblad*, 14 December 1991; *NRC-Handelsblad*, 17 December 1991.

85 This box is based on Smaal & Nienhuis, *Op. cit.*.

86 *Cf. Driemaandelijks Bericht Deltawerken*, (1981)95 and H.L.F. Saeijs, 'Conditioneren; Lessen uit 20 eeuwen waterbouwkunde en omgaan met water,' *Driemaandelijks Bericht Delta-werken*, (1988)123/124, 695-716.

87 Interview Saeijs, 6 February 1995; Saeijs, *Op. cit. 1982.*

88 *Cf.* H.J. van der Windt, *En dan: wat is natuur nog in dit land?; Natuurbescherming in Nederland 1880-1990* (Amsterdam/Meppel: Boom, 1995), 210.

89 *Ibid.*.

90 *Cf. Ibid.*, 225-226.

91 *Cf.* Saeijs, H.L.F. (1976), 'Milieukunde als basis voor inrichting en beheer', in Rijkswaterstaat Deltadienst (ed.), *De Delta, een Alma Mater?; Lessen van 20 Jaar Deltawerken*, 7-18.

92 Saeijs, *Op. cit. 1982*, 19.

93 Saeijs, *Op. cit. 1982.* See also Saeijs, *Op. cit. 1988*; Interview Saeijs, 6 February 1995.

94 *Cf.* I. de Vries, P.J.A. Baan, L.W.G. Higler, *et al.*, *Ecologische aspecten van integraal waterbeheer* (Rijswijk: RMNO, 1989), Publikatie RMNO Nr. 41, 27.

95 Interview Goemans, 12 October 1995.

96 This box is based on Saeijs, *Op. cit. 1988*; Interview Saeijs, 6 February 1995; De Vries *et al.*, *Op. cit.*;Van der Windt, *Op. cit.*, 221; *H_2O* 15(1982)24, 641-645; 15(1982)16, 406-411; 15(1982)19, 527-528; 15(1982)25, 675-676; Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer & Ministerie van Landbouw en Visserij, *Derde Nota Waterhuishouding* (Den Haag: SDU, 1989); H. Beerda, 'Waterzuivering doorgrond; een onderzoek naar grondhoudingen ten opzichte van de natuur in beleid en praktijk van industriële en gemeentelijke afvalwaterzuivering,' Afstudeerscriptie WWTS, vakgroep Systematische Wijsbegeerte, Universiteit Twente, Enschede 1993.

97 For the integrated water management approach see, for example, De Vries *et al.*, *Op. cit.*; H.L.F. Saeijs, 'Geleide ecologie,' *Waterschapsbelangen,* 1986, 667-671; Saeijs, *Op. cit. 1988;* Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer & Ministerie van Landbouw en Visserij, *Derde Nota Waterhuishouding* (Den Haag: SDU, 1989) and *H_2O*, 23(1990)23, 630-632; 25(1992)11, 274-280; 25(1992)13, 342-348 and 25(1992)21, 574-578.

98 De Vries *et al.*, *Op. cit.,* Van der Windt, *Op. cit.*, 222.

99 Van der Windt, *Op. cit.*, 222.

100 Interview Saeijs, 6 February 1995; *Driemaandelijks Bericht Deltawerken*, (1981)95.

101 Van der Windt, *Op. cit.*, 222; Saeijs, *Op. cit. 1988*, 668.

102 *Cf. H_2O* 25(1992)11, 274-280 and 25(1992)13, 342-348 where the water management system is presented as the 'meeting point' of natural (ecological) systems, societal interests and policy and management. *Cf.* also Saeijs, *Op. cit. 1982.*

103De Vries *et al.*, *Op. cit.*, 23.

104 *Ibid.*, 36.

105 This is exemplified in the policy analysis approach. *Cf.* interview Nieboer, 5 December 1994.

106 Interview Saeijs, 6 February 1995; Saeijs, *Op. cit. 1982.*

107 *Cf. Driemaandelijks Bericht Deltawerken*, (1978)85, 231-251; (1979)89, 457-460; (1979)90, 509-512 and (1984)107, 389-394. In the mid sixties, landscape gardeners and recreational experts were - for probably the first time - involved in the design of a coastal barrier, the *Brouwersdam*.

108 *Driemaandelijks Bericht Deltawerken*, (1981)95, 236-239.

109 With respect to engineering firms, see next case study. With respect to Delft Hydraulics, *cf.* Pastoors, *Op. cit.*. Delft Hydraulics now also is active in policy analysis.

110 Also in other countries the *Oosterschelde* project and the striving for integrated water management may effect the design of coastal barriers. In 1993, Rijkswaterstaat achieved the first *International Coastal Zone Award.* Until now, few countries have shown comment to a more integrated approach to estuaries and the design of coastal barriers. Often ecological considerations are integrated in an unsatisfactory way or when the project is well under way (as was also the case in the Delta Project) (*Driemaandelijks Bericht Deltawerken*, (1983)105,

261-265; Saeijs, *Op. cit. 1982*, 392-393; Westen & Colijn, 572-573; Interview Nienhuis, 20 February 1995).

111 On the *Nieuwe Waterweg* see, for example, De Boer, *Op. cit.*; Interview Saeijs, 6 February 1995; *Volkskrant*, 18 February 1995; *UT-Nieuws*, 16 March 1995 and *Cement* 45(1993)5, 6-11.

112 This box is based on de Boer, *Op. cit.; Sa*eijs, *Op. cit. 1992*, 392; Westen & Colijn, *Op. cit.*, 572; *Volkskrant* 17 January 1995, 17 February 1996, 6 April 1996.

113 One of the main general constraints for the implementation of integrated water management are the existing policy and management structures which are not tuned to the new approach (see de Vries *et al.*, *Op. cit.*).

114 Rijkswaterstaat, *Milieuvriendelijke oevers* (PMO rapport nr. 3) (Delft: Dienst Weg- en Waterbouwkunde, 1989), 39.

115 In this story, I do *not* deal with constructions that have as main function to embank the land. Such constructions like dikes have mostly been built tot protect the land against the water in case of high water levels or floods and are nowadays often defined as the upper limit of the waterside bank. The design and construction of such dike constructions orginates from a somewhat different tradition than the design and construction of waterside banks and bank protections. Generally speaking, dike constructions are more 'heavy' constructions, designed for more extreme circumstances than bank constructions. Design and constructions techniques are often more sophisticated. Dikes then are part of another technological regime than the regime of waterside banks that will concern me here.

116 Nederlandse Vereniging voor Kust- en Oeverwerken, *Kust en oeverwerken in praktijk en theorie* (Rotterdam: Nederlandse Vereniging voor Kust- en Oeverwerken, 1980).

117 Werkgroep Rivieroevers van de Natuurwetenschappelijke Commissie van de Natuurbeschermingsraad, 'De versteniging van de oevers van de grote rivieren; Enige invloeden van waterstaatswerken op natuur en landschap' (1979).

118 *Ibid.*.

119 See, for example, P.I.M. de Kwaadsteniet, *Natuurlijke oevers in beweging; Handleiding voor inrichting en beheer van riet- en andere oevers* (Utrecht: Stichting Landelijk Overleg Natuur- en Landschapsbeheer (LONL) & Samenwerkingsverband 'Alsjeblieft ... niet in 't Riet' (NIR), 1990).

120 Werkgroep Rivieroevers van de Natuurwetenschappelijke Commissie van de Natuurbeschermingsraad, *Op. cit.*, 1, my translation.

121 De Kwaadsteniet, *Op. cit.;* 'Natuurvriendelijke oevers,' special *Recreatie & Toerisme*, 1990, especially page 14; *Waterschapsbelangen*, (1984), 463-477; *Waterschapsbelangen*, (1986), 655-657. The NIR started, in 1974, as a campaign for the conservation of reed-banks by the recreational organization ANWB. In later years, The ANWB was joint by a number of other organizations, resulting in the cooperative body NIR. Apart from an information campaign - directed at the users of reed-banks - the NIR initiated a number of investigations into the possibilities of ecologically sound banks. In 1986, a report on the causes of the deterioration of reed-banks and the possibilities for recovery was published. In 1988 a study of twenty eight bank situations followed.

122 This guidebook treated various kinds of banks and their possible functions. It presents design guidelines for administrators who want to design and construct ecologically sound banks. In general, it is advised to make the transition from water to lade gradual. So, vertical constructions should only be used if necessary for other reasons.

123 De Kwaadsteniet, *Op. cit.*, 6, my translation.

124 *Cf.* interview Boeters and Boks; Werkgroep Rivieroevers van de Natuurwetenschappelijke Commissie van de Natuurbeschermingsraad, *Op. cit.*, 1, *Waterschapsbelangen*, 1978, 292.

125 This section is mainly based on Nederlandse Vereniging Kust- en Oeverwerken, *Handboek oeverbeschermingsconstructies* (Rotterdam: K&O, 1983); Nederlandse Vereniging voor Kust- en Oeverwerken, *Kust en oeverwerken in praktijk en theorie* (Rotterdam: Nederlandse Vereniging voor Kust- en Oeverwerken, 1980) and interview Boeters and Boks; interview Markerink, 30 November 1994; interview Nieboer, 5 December 1994; interview Paans, 14 November 1994; interview Van Selm, 15 December 1994. For more details, see Appendix 3.

126 Interview Boeters and Boks; interview Markerink, 30 November 1994; interview Nieboer, 5 December 1994.

127 Nederlandse Vereniging Kust- en Oeverwerken, *Op. cit. 1980 and* 1983. Interview Boeters and Boks; interview Markerink, 30 November 1994; interview Nieboer, 5 December 1994.

128 Nederlandse Vereniging Kust- en Oeverwerken, *Op. cit. 1980 and* 1983. For more details, see Appendix 3.

129 *Ibid.*.

130 See Appendix 3.

131 Information from internet-site: http://www.bouwweb.nl/CUR/curpub.html and CUR leaflets.

132 Financing of activities largely takes place on project basis by the knowledge demanding parties. In some cases, the government subsidies projects. For a small part, CUR is financed by the collective funds of the building sector, the supplying industry and municipalities.

133 Interview Boeters and Boks; interview Markerink, 30 November 1994.

134 Interview Boeters and Boks.

135 Ministerie van Verkeer en Waterstaat en Rijkswaterstaat, *Meerjarenplan oevers; Actergronden* (Delft: Dienst Weg- en Waterbouwkunde, 1989).

136 Interview Boeters and Boks; interview Markerink, 30 November 1994.

137 On the Water Boards see: B. de Goede, J.H.M. Kienhuis, J.G. Steenbeek, *et al.* (eds.), *Het Waterschap; Recht en werking* (Deventer: Kluwer, 1982); J.J. de Graeff, O. van der Heide, J.M.A.M. Mouwen, *et al.*, *Het Waterschap in kort bestek* (Den Haag: VUGA, 1990); C. Sneep, *Het Waterschapsbestuur; Kanttekeningen bij de ontwikkeling van het Waterschap tot functionele representatie-democratie* (Deventer: Kluwer, 1980), dissertation. See also Appendix 3 on the regime of sewage treatment.

138 *Cf.* interview Van Selm, 15 November 1994.

139 This section is based on Anonymus, 'Handboek natuurvriendelijke oevers verdedigt constructief-ecologisch optimum,*' Wegen*, (1994)3, 10-13; H.D. van Bohemen, D.A.G. Buizer & A. Littel (eds.), *Natuurtechniek en waterstaatswerken* (Utrecht: Stichting Uitgeverij Koninklijk Nederlandse Natuurhistorische Vereniging in samenwerking met Dienst Weg- en Waterbouwkunde Rijkswaterstaat, 1990); H.D. van Bohemen (ed.), *Milieuvriendelijke oevers in de praktijk; Verslag van de studiedag, gehouden op 1 november 1989 te Den Haag* (PMO rapport nr. 15) (Delft: Rijkswaterstaat Dienst Weg- en Waterbouw, 1989); Civieltechnisch Centrum Uitvoering Research en Regelgeving, *Milieuvriendelijke oevers; Voorlopige leidraad voor een integrale benadering van ontwerp, aanleg en beheer van oevers* (CUR rapport nr. 90-4, PMO rapport nr. 13) (Gouda: CUR, 1990); Civieltechnisch Centrum Uitvoering Research en Regelgeving & Directoraat-Generaal Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, *Symposium "Natuurvriendelijke oevers" 13 januari 1994 World Trade Center te Rotterdam* (Gouda: CUR, 1994); Civieltechnisch Centrum Uitvoering Research en Regelgeving & Directoraat-Generaal Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, *Natuurvriendelijke Oevers* (Gouda: CUR, 1994), Rapport 168 CUR; P.I.M. de Kwaadsteniet & H.E. van Capelleveen, *Signaaladvies natuurvriendelijke oevers* (Rijswijk: RMNO, 1993), Publikatie RMNO nr. 85; Oranjewoud, 'Milieuvriendelijke oevers in relatie tot Meerjarenplan Oevers' (PMO rapport nr. 11) (1990); Rijkswaterstaat, *Milieuvriendelijke oevers* (PMO rapport nr. 3) (Delft: Dienst Weg- en Waterbouwkunde, 1989); Rijkswaterstaat, *Oeveronderzoek bij de Dienst Weg- en Waterbouwkunde; vijfjarenplan ('90-'94)* (Delft: Dienst Weg- en Waterbouwkunde, 1990); J. Stuip, '"Integrale aanpak oevers geeft milieu de ruimte"; Milieuvriendelijke oevers in Derde Nota Waterhuishouding,' *Land + Water*, juli/augustus 1990, 82-85; Interview Boeters and Boks.

140 *Cf.* Rijkswaterstaat, *Milieuvriendelijke oevers* (PMO rapport nr. 3) (Delft: Dienst Weg- en Waterbouwkunde, 1989), especially page 12 and 39; *Land + Water nu*, (1989)4, 43-44; Waterschapsbelangen, (1992)21, 850-853; *Otar* 78(1993)6, 192-197 and (1995)4, 123-127.

141 Rijkswaterstaat, *Milieuvriendelijke oevers* (PMO rapport nr. 3) (Delft: Dienst Weg- en Waterbouwkunde, 1989), 39, my translation.

142 *Ibid.*, 1.

143 *Ibid.*, 38.

144 *Ibid.*.

145 In 1987, CUR committee C59 was established to formulate guidelines on the 'constructive aspects of ecologically sound banks.' Representatives of different involved parties in the regime of waterside banks got a seat in this committee. The original aim was to develop guidelines for constructive and hydraulic aspects of ecologically sound banks. Later, the task of the committee was broadened as to include guidelines for all aspects of the design of ecologically sound banks. In 1990, a preliminarily guideline was presented.

146 Rijkswaterstaat, *Op. cit. 1989*, 11, my translation.

147 *Ibid.*, 22, my translation.

148 Proponents of ecologically sound banks have regularly stressed that the bank should not be seen as a line, as was traditionally the case, but as a stroke, an area constituting a transition zone from land to water (Interview Boks, H.E.J. Simons & J.T. Klein Breteler, 'Natuur in oevers ... Een avontuur,' in Civieltechnisch Centrum Uitvoering Research en Regelgeving & Directoraat-Generaal Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, *Symposium "Natuurvriendelijke oevers" 13 januari 1994 World Trade Center te Rotterdam* (Gouda: CUR, 1994), 41-49).

149 Differences existed between banks with respect to the degree of protection required, the importance of recreational functions, etcetera. However, in each concrete case, the functions to be fulfilled were often seen as clear-cut and requiring not much deliberation.

150 R.E.A.M. Boeters, 'Een nieuwe rolverdeling; De ecoloog als architect en de waterbouwer als constructeur,' in Civieltechnisch Centrum Uitvoering Research en Regelgeving & Directoraat-Generaal Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, *Symposium "Natuurvriendelijke oevers" 13 januari 1994 World Trade Center te Rotterdam* (Gouda: CUR, 1994), 33, my translation.

151 *Ibid.*, 34, my translation.

152 Civieltechnisch Centrum Uitvoering Research en Regelgeving & Directoraat-Generaal Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, *Natuurvriendelijke oevers* (Gouda: CUR, 1994), Rapport 168 CUR, 31-32, my translation.

153 *Ibid.*, 32, my translation.

154 *Ibid.*, 32-33, my translation.

155 *Ibid.*, 34, my translation.

156 *Ibid.*, 29, my translation.

157 *Ibid.*, 29, my translation, emphasis in original.

158 *Ibid.*, 31.

159 See, for example *ibid.*, page 41-42 and 148.

160 The description of the developments in water management and the striving for integrated water management is based on the literature cited in the notes 96 and 97.

161 In 1970, the Dutch Pollution of Surface Waters Act or WVO (*Wet Verontreiniging Oppervlaktewateren*) was approved in the Netherlands. This gave an impetus to water quality management and sewage and waste water treatment. See also Chapter 5 and Appendix 3.

162 Interview van Selm, 15 November 1994; Van der Windt, *Op. cit.*, 221. One reason why ecologists and biologists began to be employed by Rijkswaterstaat was the establishment of the Environmental Division of the Delta department as we have seen in Section 6.1. After the Delta Project, the Delta Department became part of the newly established Department Tidal Waters of Rijkswaterstaat. Later, this became the National Institute for Coastal and Marine Management or RIKZ (*Rijksinstituut voor Kust en Zee*). The Department Tidal Waters, and later the RIKZ, were engaged in environmental tasks and played a role in the development of policy and tools for integrated water management.
With respect to *fresh* water management, ecologists and biologists merely began to be employed by the RIZA and the Regional Directorates of Rijkswaterstaat. RIZA initially was the abbreviation of the Netherlands Institute for the Purification of Waste Water (*Rijksinstituut voor de Zuivering van Afvalwater*). Until 1971, the RIZA was independent from Rijkswaterstaat. Until then, the institute - established in 1920 - had been mainly responsible for the building of sewage treatment plants. After 1970, its responsibility shifted toward the area of water quality management. In 1985, the RIZA also became responsible for water quantity management

issues. With this shift, fresh water quantity and quality issues were integrated within Rijkswaterstaat. In 1990, the name of the institute was changed to Netherlands Institute for Integral Fresh Water Management and Waste Water Treatment. The acronym stayed RIZA *(Rijksinstituut voor Integraal Zoetwaterbeer en Afvalwaterbehandeling*.) The RIZA has undertaken a number of initiatives and activities with respect to integrated water management and ecologically sound banks.

163 *H_2O*: 8(1975)5, 86-94; 8(1975)24, 501-506; 9(1976)8, 154-160; 9(1976)21, 438-440; 10(1977)7, 169-170; 12(1977)14, 321-323; 10(1977)14, 329-331; 14(1981)1, 11-14; 20(1987)21, 514-518; 24(1991)4, 84-87.

164 Interview Van Selm, 15 November 1994.

165 Saeijs, *Op. cit*; interview Nienhuis, 20 February 1995; interview Saeijs, 6 February 1995; interview Van Selm, 15 November 1994.

166 Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer & Ministerie van Landbouw en Visserij, *Derde Nota Waterhuishouding* (Den Haag: SDU, 1989).

167 Interview Markerink, 30 November 1994 and interview Van Selm, 15 November 1994.

168 See, for example, P.I.M. de Kwaadsteniet & H.E. van Capelleveen, *Signaaladvies natuurvriendelijke oevers* (Rijswijk: RMNO, 1993), Publikatie RMNO nr. 85, especially page 8 and 21.

169 This applies to Water Boards with a task with respect to water quantity management. Water Boards with a water quality management tasks or combined tasks were already obliged to formulate policy plan since 1982 when the Dutch Pollution of Surface Water Acts was changed (*H_2O* 16(1983)10, 426).

170 Pastoors, *Op. cit.* (with respect to Delft Hydraulics); interview Nieboer, 5 December 1994; interview Reitsma, 7 December 1994; interview Van der Graaf, 8 December 1994; information leaflets engineering firms.

171 Interview Reitsma, 7 December 1994.

172 De Vries *et al.*, *Op. cit.*.

173 De Kwaadsteniet & Van Capelleveen, *Op. cit.*

174 *Ibid.*, 22.

175 *Ibid.*, 14.

176 Interview Boeters and Boks; interview Reitsma, 7 December 1994.

177 J.S. Peters, M.H.C. van den Hark & C. Bakker, *Ecologische advisering natuurvriendelijke oevers: Een methodische leidraad* (Lelystad: RIZA, 1991), RIZA Nota nr. 91.086; de Kwaadsteniet & van Capelleveen, *Op. cit.*, 22.

178 Peters *et al.*, *Op. cit.*, 5.

179 *Ibid.*.

180 Interview Boeters and Boks; interview Reitsma, 7 December 1994.

181 Interview Boeters and Boks; interview Markerink, 30 November 1994; interview Nieboer, 5 December 1994; interview Paans, 14 November 1994; interview Van Selm, 15 December 1994.

182 *Waterschapsbelangen* (1990)17, 602.

183 *Ibid.*.

184 *Ibid.*, 603.

185 *Ibid.*, 602.

186 De Vries *et al.*, *Op. cit.*.

187 *Ibid.*.

188 *Cf. Driemaandelijks Bericht Deltawerken*, (1976)75, 228-232.

189 For the ‘consumption junction,’ see Schwartz Cowan (1987).

7

Safe and Silent?

Aero-engines and Nuclear Reactors

Aero-engines and nuclear reactors are, despite their many differences, technologies that are both highly complex in terms of interrelating parts and the variety of design criteria that have to be met. Technological and scientific insights play an important role in the design of these technologies. Both technologies are designed and produced by a few large companies, which are - in the case of nuclear reactors, increasingly - operating internationally. Companies in this business have to spend large sums on R&D and the production of innovative designs. As a result, they face large commercial risks. Commercial failures are not uncommon and sometimes result in bankruptcy, takeovers or mergers.
The complexity of aero-engines and nuclear reactors and the interrelationships among the various component parts imply that after more radical innovations have taken place, there is plenty of room for smaller innovations and improvements. Innovations in both technological regimes take place in successive generations. The innovation pattern is R&D-dependent, *i.e.* ideas for more radical innovations arise from scientific and technological developments which take place at the universities, government financed research institutes and in the R&D laboratories of the firms producing aero-engines and nuclear reactors.

As with many complex technologies for which the rate of innovation is high, aero-engines and nuclear reactors also produce a host of secondary effects. In this chapter, I focus on particular secondary effects of both regimes fed back to the existing technological regimes during a process of transformation. These secondary effects are the noise of aero-engines and the safety risks of nuclear reactors.
In the aero-engine story, we will see how aircraft noise around airports was increasingly conceived as a problem by airport neighbors when a new type of aero-engine, the turbojet, was introduced in the late fifties and early sixties. This aggression was made manifest through the complaints of airport neighbors. Airports and aviation agencies subsequently formulated noise rules. Eventually, noise became an important design criterion in the technological regime of aero-engines, alleviating but not completely solving the noise problem.
In the nuclear reactor story, a new guiding principle for nuclear reactor design was proposed by a group of maverick scientists that became involved via a demand. They proposed inherent safety as a new guiding principle. This principle implies that the safety of nuclear reactors should be based on natural laws, instead of on active safety systems that might fail in case of a nuclear accident. Inherent safety was advocated in response to public protests and public doubts about the safety of nuclear reactors. Meanwhile, it was a response to several problems within the technological regime of nuclear reactors like lengthy licensing processes and declining economic prospects.

The R&D-dependent innovation pattern in the technological regimes of aero-engines and nuclear reactors enabled the studied processes of transformation because researchers proactively undertook R&D activities. The high rate of technological change and the fact that innovation took place in successive generations further meant that noise abatement and inherent safety features could be incorporated in next-generation designs of aero-engines and nuclear reactors.

7.1 Silent Aero-Engines[1]

Until the Second World War, aircrafts were fired by piston engines with propellers. Between the forties and early seventies, the turbojet gradually replaced the piston engine with propeller as means of propulsion for many types of aircrafts. The turbojet was initially developed for military aircrafts. Later, also turbojets for civil aircrafts were developed.

In the late fifties and early sixties, the civil turbojet was introduced on a new generation of aircrafts, which was brought onto the market by the large American aircraft manufacturers. By the end of the sixties, there were more than two thousand jet-powered aircrafts and the jet had surpassed propeller aircrafts as means of flying in civil aviation.[2]

Turbojets had an important secondary effect that, when made manifest by outsider groups, initiated a process of transformation with respect to the technological regime of *civil* aero-engines. Planes using turbojets produced far more noise than the traditional propeller-driven aircrafts had done.[3] This led to a growing number of complaints of airport neighbors.[4] When in the late fifties and early sixties a large number of jet-powered aircrafts entered service, the noise produced created such a nuisance that citizens' protests became louder and louder.[5]

In 1962, the American Supreme Court decided that airport operators could be held liable for damage resulting from aircraft noise.[6] Therefore, some airports felt obliged to set noise limits for aircrafts and to install noise monitoring systems.[7] Authorities like the American aviation agency FAA began to issue operating procedures for takeoff and landing that would relieve noise annoyance.[8]

Several measures were taken by individual airports and aviation agencies like the FAA to relieve the noise problem.[9] Some of these measures, like night curfews, implied a reduction in aircraft movements at airports. Such measures were commercially unattractive for airlines and were seen as damaging for the long-term (economic) interests of the aviation industry.[10] As an effect, airlines and airports got a (commercial) interest in the development of more silent aircraft engines that, as they hoped, would eventually alleviate the reduction of aircraft movements.[11]

Aviation agencies got an interest in more silent aircrafts too. They were urged by complaining, protesting and litigating citizens to do something about aircraft noise. They did so not only out of social responsibility but also because they realized that ongoing societal complaints and 'anarchistic' anti-noise measures of individual airports might hamper commercial interests and ultimately the viability of commercial flight.[12]

In the sixties, the American FAA began to discuss legal measures with respect to noise features of future aero-engine and aircraft designs.[13] It opened a dialogue with industry and among countries. At an international conference in London in 1966, it was proposed to control the manufacturers of aircrafts by means of certification. Traditionally, certification had been merely concerned with safety standards, now it was to include noise requirements as well. The FAA wrote a letter to the US aircraft manufacturers, stressing the pressing nature of the noise problem:

Noise has become a problem of national concern in our society. People are becoming increasingly disenchanted with illusory statements to the effect that increasing noise levels are synonymous with industrial progress.[14]

The letter not only noticed the noise problem but also warned for proposed federal action. Further, the proposed framework for legal action, the practical structures for certification and a special noise descriptor, the so-called EPNdB (Effective Perceived Noise Level), were described.
In 1969, the FAA published a Notice of Proposed Rule Making (NPRM 69-1) for aircraft noise. In 1971, NPRM 69-1 became part of the American legislation after a round of public and industrial response. The final rules were laid down in a new section of the Federal Aviation Regulations: FAR Part 36.
International steps were undertaken too. In 1969, the International Civil Aviation Organization (ICAO) created a special Committee on Aircraft Noise (CAN). Possibly spurred by the American rules, the ICAO in 1971 issued rules that much resembled Far Part 36. These rules were laid down in an addendum, Annex 16, to the 1944 Chicago Convention on Civil Aviation.[15]
The noise certification rules of the early seventies could rather easily be met by aircraft and aero-engine manufacturers. One reason was that airframe and aero-engine companies knew beforehand that the FAR and ICAO regulations were upcoming and that they, proactively, undertook noise research and developed new technology.[16] Another reason was the introduction of a new variation to the turbojet in the early seventies, the so-called high-bypass turbofan. Although this new type of aero-engine was not developed for reasons of noise, it offered good opportunities to reduce the noise of aero-engines.

In this story, I describe the process of transformation toward more silent aircrafts and aero-engines in more detail. I focus on the regime of *civil aero-engines*. For a long time, the aero-engine was the major source of aircraft noise. Therefore, diminishing aircraft noise meant silencing the aero-engine.[17] I further focus on the larger types of aero-engines used for the larger passengers' aircrafts. At the moment, such aero-engines are produced by three large companies: Pratt & Whitney, Rolls Royce and General Electric.[18]
This story consists of three parts. In Section 7.1.1, I discuss the development of noise research and more silent aero-engines. In Section 7.1.2, the issuing of new noise certification rules since the seventies will be discussed. The transformations in the regime of aero-engines will be resumed in Section 7.1.3.

7.1.1 The Development of More Silent Aero-Engines

When noise certification rules were enforced in the early seventies, it proved possible to develop more silent aero-engines without too many penalties in terms of other design criteria like efficiency, reliability and maintainability. This was due to the development of the so-called high-bypass turbofan. This development was initially not motivated by noise concerns but by considerations of efficiency. To understand how and why this new aero-engine was developed, the innovation pattern in the technological regimes of aero-engines has to be described in some detail.

Generations of Aero-engines

Innovation in aero-engine design takes places in successive generations. Now and then more radical departures from existing technology take place, followed by periods of more calm, incremental innovation. Typical phases of innovation in *civil* aviation distinguished by analysts are:[19]

- 1910's: early flight; first (wooden) airframes combined with aero-engines deriving from automobile applications (Otto-engines). The engines were not very reliable.

- 1930's: development of well-streamlined all-metal skin planes with more powerful and reliable piston engines-propellers. In this period, innovations like the variable pitch propeller took place. The DC-3 was prototypical for this generation.

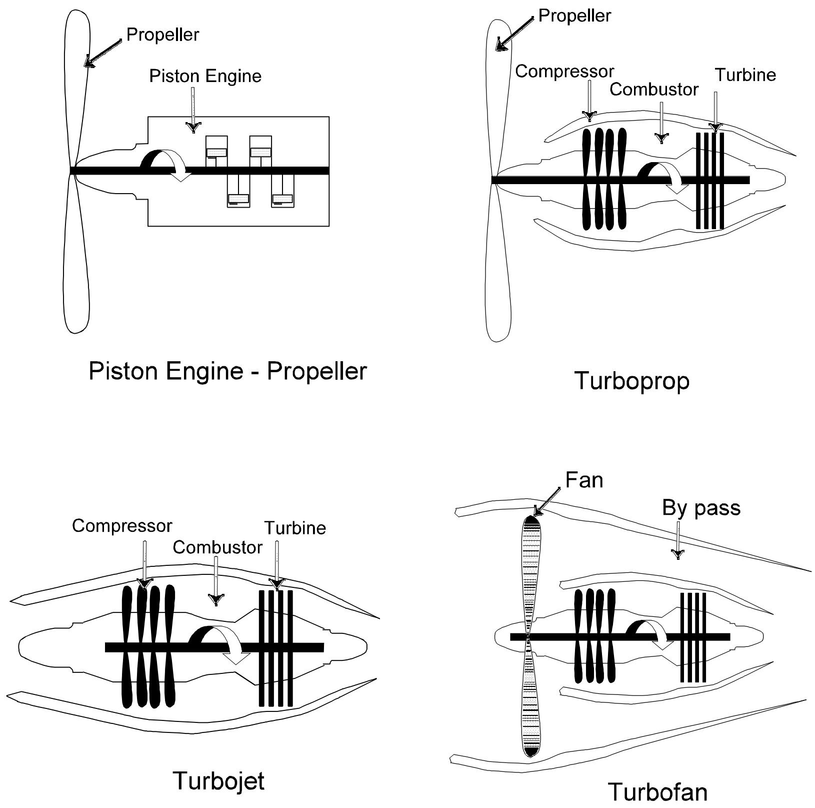
- Late 1950's and early 1960's: narrow-body jet aircrafts with swept back wings and turbojets or low-bypass turbofans as engines. This period was characterized by aircraft types like the Boeing 707 and the DC-8.

- Late 1960's and early 1970's: wide-body aircrafts with high-bypass turbofans. Aircraft types like the Boeing 747, DC-10, L1011.

These four phases each relate to a new generation of aircrafts and a new generation of aero-engines. It was the third of these generations that was to introduce the airport noise problem. The fourth that partly helped to solve it.

Looking at aero-engines, the major development between the forties and the seventies was the development of the turbojet and the development of two subsequent generations or variations to the turbojet: the low-bypass and the high-bypass turbofan. Especially the latter eventually enabled the development of more silent aero-engines.

A main motive for the development of the low-bypass and later the high-bypass turbofan was the striving for efficiency. Compared with the propeller, the turbojet had brought a new tradeoff between speed and efficiency.[20] The turbojet made it possible to fly at higher speeds, but at the speed at which the earlier propeller aircrafts had flown, it was less efficient than those propeller aircrafts. This was because the turbojet accelerated a small amount of air to a very high speed, while propeller aircrafts had accelerated a larger amount of air to a smaller speed. This meant that the turbojet wasted away much more (kinetic) energy than the propeller at lower speeds. Therefore, the propeller was a more efficient means of propulsion at lower subsonic speeds. For flight at higher subsonic speed, neither the piston-engine propeller system nor the turbojet was considered optimal in terms of efficiency. A compromise between the piston-engine propeller system and the turbojet was therefore sought and found in the turboprop (see Figure 7.1).[21] A turboprop consists



Piston-Engine Propeller
The piston engine drives the propeller which accelerates a large amount of air to a relatively low speed.

Turboprop
A gas-turbine drives a propeller. The net thrust results from the propeller and the exhaust speed of the burned fuel.

Turbojet
A gas-turbine accelerates a relatively low amount of air to a relatively high speed. The thrust results from the speed of the exhaust air.

Turbofan
Part of the air by-passes the combustion chamber. The turbine drives one or more fans. These fans accelerate the bypassing air, which mixes at the back with the (faster) burned fuel. The net thrust result from the speed of the exhaust air.

Figure 7.1 *Types of Aero-engines*

of a gas-turbine driving a propeller. The net thrust results from both the propeller and the exhaust speed of the burned fuel. The turboprop was developed for commercial transport somewhat earlier than the turbojet.[22]

While the turboprop has proved an attractive propulsion device for specific types of aircrafts (flying at particular speeds), it was still felt in the aero-engine regime that it was not the ideal propulsion device for flight at higher subsonic speeds.[23] Therefore, a compromise between the turbojet and the turboprop was looked for. This resulted in a jet in which part of the air bypassed the combustion chamber and was accelerated by one or more fans. The bypassing air then mixed with the (faster) burned fuel giving the device its net thrust. This kind of aero-engine was called a bypass-engine or turbofan. In 1946, the idea of a turbofan had already attracted attention at the Metropolitan Vickers Company in Manchester, which was then producing turbojets.[24] The problem Vickers and later other companies faced was twofold.[25] In the first place, a bypass-engine would imply higher temperature in the compressor and turbine. Given the available materials and the state of turbine-cooling technology, this seemed an insolvable problem at the time. In the second place, no clear market for turbofans existed. Such a market did not develop until the late fifties when the first big jet aircrafts came into service. By then, it had also technically become possible to design a bypass-engine.

The first generation of jet-powered aircrafts used either pure turbojets or turbofans with a small bypass ratio. The bypass ratio is the ratio between the air bypassing the combustion chamber and the air entering it. The higher the bypass ratio the more energy efficient the aero-engine. Turbofans with higher bypass ratios are technically more difficult to achieve. Therefore, the early turbofans had a relatively low bypass ratio of about 0.6. Later, turbofans with higher bypass ratios came technically feasible due to developments in materials science and turbine-cooling technology.[26] In the seventies turbofans with a bypass ratio up to five or six, so-called high-bypass turbofans, were introduced at the new generation of wide-body aircrafts that was then introduced by the aircraft manufacturers. These new aircrafts were one of the first new aircraft designs that had to meet the noise certification rules issued by the FAA and the ICAO. The introduction of the high-bypass turbofan made it easier to meet the new noise rules. This was so because the speed of the exhaust air of a high-bypass turbofan is much lower than the speed of the exhaust air of the turbojet and low-bypass turbofans. The noise of the exhaust air had been the main noise source of turbojets and low-bypass turbofans.

The high-bypass turbofan was, however, not a silent aero-engine per se. While the noise of the outlet air was seriously reduced, other noise sources were more significant than in the case of low-bypass turbofans. The high bypass engine would probably have produced as much noise as the low-bypass turbofan if no additional design measures had been taken.[27] These additional design measures were made possible by proactive noise research done by government research institutes like the NASA and by the aero-engine and aircraft manufacturers.

Aero-engine Noise Research[28]

Noise research on aero-engines was already carried out before the introduction of the turbojet.[29] Very important for noise research on turbojets was an article published by Lighthill in 1952.[30] In this article, Lighthill argued that the turbulent mixing of the jet exhaust with the surrounding air was the main source of turbojet noise. Lighthill also gave a quantitative formulation of the relationship between exhaust speed and turbulence noise. Lighthill's publication had the important practical implication that more silent aircraft engines were to be sought either in lower exhaust speeds or in rapid mixing of the exhaust and the surrounding air.

In hindsight, Lighthill's publication laid the ground for a new branch of science: aeroacoustics. This is an interdisciplinary endeavor integrating insights from acoustics and fluid dynamics.[31] This new area of scientific inquiry has produced insights in the generation and propagation of sound that originates in (high speed) flows.

In the fifties, research on engine noise was carried out by manufacturers, governmentally funded research institutes and universities in manufacturing countries. This research also required the development of test methods and the establishment of test facilities. An important type of test facility is the so-called jet noise research rig. At such facilities the noise of engine parts (fan, compressor, turbine) or of complete engines can be tested. At research rigs, noise is usually measured in static circumstances. This means that the inlet air at static facilities has to be treated in order to make the data obtained relevant for in-flight situations.[32] In the course of time, different kinds of special facilities to observe speed effects have been developed. In France, an experimental train formed the basis for a 'forward-speed' test facility. By now, wind tunnels have become commonly used to examine speed effects.[33]

Computer models as well have been developed to predict the noise of aero-engines. For noise research and development purposes, especially computer models for single engines are important. The noise of (new) aero-engines can, for example, be predicted by intra- or extrapolation from other power plants. If data on comparable plants are not available, noise may be predicted with computer codes for individual engine parts.[34]

In the sixties, impending certification rules and growing (commercial) interest in less noisy aircrafts consolidated the growth in noise research. In this decade, the number of scientists working on noise issues rose tenfold in the UK.[35] Many new noise test facilities were established. In the USA, NASA and the Department of Transport carried out a large amount of noise research and granted 'all who had the capability of conducting noise research' valuable contracts.[36]

With respect to the development of more silent aero-engines, the introduction of the high-bypass turbofan was of special importance. Lighthill's earlier mentioned publication had implied two different strategies for reducing the noise of aero-engines, *i.e.* 1) (more) rapid mixing of the exhaust air with the surrounding air and 2) lowering the speed of the exhaust air. Before the introduction of the high-bypass turbofan, the first strategy was the most popular.[37] So-called suppressors were used to mix the jet exhaust air with the surrounding air.[38] These suppressors, however, implied a penalty in performance and energy efficiency due to internal thrust lost, additional external drag and added weight. This made suppressors not very attractive.

The development of the high-bypass turbofan made the second strategy, lowering the speed of the exhaust air, technically feasible. However, the high-bypass turbofan would probably have produced as much noise as the low-bypass turbofan if no additional design measures had been taken.[39] Especially the fan was a major (new) source of noise in the high-bypass turbofan. In the event, fan noise was reduced by using ideas of aeroacoustic and noise researchers. In 1962, Tyler and Sofrin had shown that a clever choice of the number of blades in the rotating and static parts of a fan resulted in the 'cutoff' of some fundamental interaction tones.[40] Other measures related to the noise of the turbine, which had become *relatively* more prominent with the achieved reductions in fan noise. The major design measures that were eventually taken are summarized in Figure 7.2.[41] Overall, these measures amounted to a noise reduction of about 20 dB, which was enough to meet the noise certification rules of 1971.[42]

Noise Rules Met by New Technology

In the late sixties and early eighties, high-bypass turbofans were introduced at the new wide-body aircrafts. This included aircraft types like the Boeing 747, Lockheed's L1011, the Douglas DC-10 and the Airbus 300.[43] Since the aircraft and

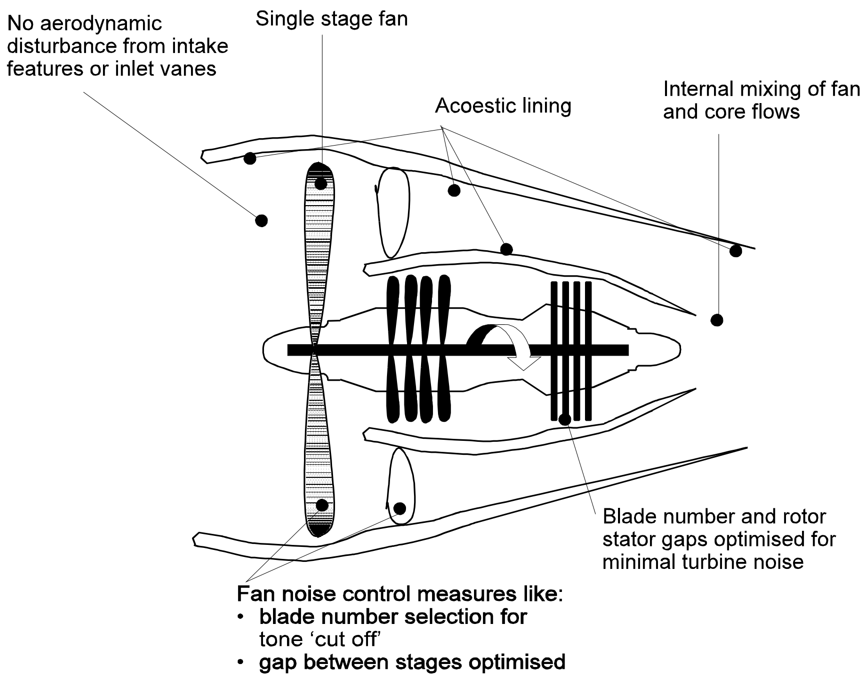


Figure 7.2 *Typical Anti-noise Measures in a High-bypass Turbofan*

aero-engine manufacturers had been warned for the upcoming certification rules and since anti-noise design measures had become available, most new designs met the certification rules. The only new aircraft (aero-engine) that required design adaptations were the follow-ups of the first Boeing 747 Jumbo jet.[44]

The noise certification rules of 1971 applied to new types of aircrafts. It was for this kind of regulation that the existing innovation pattern in the regime of aircrafts and aero-engines was particularly enabling. New types of aircrafts brought new types of engines and anti-noise technology could be developed for, and integrated in these new generations of aircrafts and aero-engines.
The noise certification rules of 1971, however, had little impact on overall airport noise just because the production of existing types of aircrafts powered by low-bypass engines did not stop.[45] So, overall noise annoyance did not lessen and public protest and outcry ragged on. In response to the still growing noise problem and public protests, the FAA and the ICAO in 1973 changed the certification requirements as to include every single new aircraft.[46] In 1976, the USA issued retrofit requirements that should be fulfilled by all aircrafts as of January 1985.[47] Several strategies stood open for airlines to meet these new certification rules.[48] One option was to do away the existing aero-engines either by scrapping entire planes or by re-engining them with more silent aero-engines. The main disadvantage of this strategy is costs; airlines will hesitate to do away aircrafts or to re-engine them as long as the aircrafts and the aero-engines are not yet depreciated. Moreover, not for all existing aircrafts re-engining options were available.[49]
A second strategy was to make the currently used aero-engines more silent.[50] This can be done by replacing or adding particular components, like absorption materials, to existing engines as to make them fit the noise rules. For such purposes, so-called hushkits have been developed. Like new generations of aero-engines, hushkits have benefitted from developments in noise research and anti-noise technology, especially from advances in acoustic lining.[51] Hushkits usually imply only a moderate improvement in noise and they may negatively influence the engine’s propulsive power and efficiency.[52] Nevertheless, for reasons of costs, hushkits have often been preferred over scrapping or re-engining the aircrafts.
Hushkits are, as a rule, not produced by the aero-engine manufacturers, but by independent firms. Some hushkit programs are backed by the large aero-engine manufacturer Pratt & Whitney.[53] Pratt & Whitney does so because it produced many of the aero-engines that are now used. Maintenance costs for these aero-engines amount to an important part of the income of Pratt & Whitney. If the engines would be replaced by aero-engines of one of the other two large manufacturers of aero-engines (General Electric and Rolls Royce), Pratt & Whitney would lose this source of income.

7.1.2 Noise Certification and Regulation[54]

In the preceding section, we saw that the R&D-dependent innovation pattern of the technological regime of aero-engines enabled noise certification in the seventies.

A main reason that it did so is that research institutes and manufacturers proactively undertook noise research and that anti-noise technology could be introduced at new generations of aero-engines and aircrafts. In other words, silencing the aero-engine was technically attainable and could be incorporated into the existing innovation pattern.

As we have seen, the regime in particular enabled noise certification for new types of aircrafts and less so for existing types or aircrafts already in use. Nevertheless, hushkits developed for older types of aircrafts also profited from noise research and the development of anti-noise technology.

More than technical constraints, economic consequences of retrofitting constrained the issuing of noise certification requirements. Below, we will see how considerations of technical and economical feasibility have continued to play an important role in the issuing of new noise (certification) rules.

Fora for Noise Regulation

Discussions about noise regulation and certification take place in a context that is somewhat broader than the technological regime of aero-engines or the technological regime of aircrafts. This context may be described as the world of commercial flight.[55] This world is not a *technological* regime because commercial flight is not a technological design activity, but it may nevertheless be seen as a regime because also around commercial flight specific interaction rules and patterns have evolved.

Within the world of commercial flight, the aircraft noise issue is addressed at three levels: local (airports), national and international. Pressures to issue noise rules are more apparent at the local and national level than at the international level.

At the local level, noise rules are issued by airports and local governments. At this level, the noise problem is actually felt and many citizens' groups of airport neighbors protesting against aircraft noise are organized locally. At this level, many actors are involved in discussions about noise regulation: airports, airlines, pilots organizations, local governments, anti-noise and environmental groups.[56]

At the national level, noise regulation is issued by the central government. Apart from the actors active at the local level, especially various government ministries and agencies are involved in discussions about noise regulation at this level. Some of them have a direct interest in the viability of commercial flight like aviation agencies and Ministries of Transport, others, like the American Environmental Protection Agency (EPA), have an interest in environmental and noise issues.

Actors at the international level include country representatives, representatives from multinational bodies like the OECD and the EU, the IATA, representing more than hundred airlines and the AACC representing airport associations.[57] All these actors have an interest in the (long-term) viability of commercial flight. Actors with a main interest in reducing aircraft noise are not directly involved at the international level.[58]

Of the actors represented at the international level, *airports* are usually proponents of more strict noise rules. Airports are directly confronted, at the local level, with complaining citizens and with local and national noise rules. *Airlines* are, as a rule, the most firm opponents of more strict noise rules. They have especially opposed retrofit rules because these rules bring extra costs for hushkits or for buying new engines or planes. Airlines have also opposed more strict noise rules for new aircrafts because they fear that eventually such new noise rules will be used as retrofit requirements. Because this expectation is shared by other actors active in aviation, noise rules for new aircrafts will probably lower the asset value of older aircrafts.[59]

The most important forum in which international noise certification is discussed is the Committee on Aviation Environmental Protection (CAEP, the successor of CAN) of the ICAO. This committee consists of representatives of fifteen countries and can only make recommendations to the ICAO if a consensus exists among its members.[60] The CAEP has established three criteria to judge the acceptability of new international noise rules: 1) the need and the effect of the measures in terms of noise regulation, 2) technical feasibility and 3) acceptability of the economic impact.[61] The second and third requirement imply that noise certification is adapted to what is considered commercially feasible in the world of commercial flight and what is considered technically attainable in the technological regimes of (civil) aircrafts and aero-engines.

Noise Certification Since the Seventies

Above, the noise certification rules of the early seventies were discussed. As we have seen during the seventies these rules were applied to all new aircrafts (not only new aircraft types) and eventually to aircrafts in use as well. At the end of the seventies, both the FAA and the ICAO issued more strict certification rules for new aircrafts. They introduced a system implying different stages (FAR) or chapters (ICAO) of aircraft noise.[62] Chapter 3 was applied to aircrafts of which the prototype was certified after 5 October 1977. These aircrafts were to meet newly issued and more stringent noise requirements.[63] Chapter 2 includes aircrafts meeting the old noise standards. Chapter 1 includes the remaining aircrafts, meeting no noise standards.

Between 1977 and the early nineties, the noise rule-making debate focused on measures to ban the operation of aircrafts not meeting Chapter 3. The lead for these measures was often taken by local airports. Initially, mainly US airports took measures against noisy aircrafts. By 1987, more than 400 US airports had issued some form of noise-control restrictions.[64] In the early nineties, it was estimated that at the world's forty busiest airports noise surcharges amount to 38% of the landing charges.[65] An airport like Dusseldorf in Germany levied twice as much landing charges for Chapter 2 aircrafts than for Chapter 3 aircrafts.[66] Other airports, like Orange County in California (USA), totally banned Chapter 2 and some Chapter 3 operations.[67]

In the eighties, local airport officials began to lobby for a phase-out of Chapter 2 aircrafts.[68] They had some success. Several national governments decided to phase out the production and use of noisier aircrafts.[69] In 1990, the ICAO decided to phase out Chapter 2 aircrafts.[70] A resolution was agreed upon implying that all Chapter 2 aircrafts have to be phased out by 2002. In the same year, the American Congress passed the Airport Noise and Capacity Act (ANCA).[71] The act had two goals. First, it aimed at a phase-out of Stage 2 aircrafts in the year 2000.[72] Second, it was to counteract the proliferation of noise restrictions by local airports. Such locally different noise rules are troublesome for airlines and, it was feared, might hamper the long-term viability and growth of commercial flight.

In 1994, the NASA started a program to develop new anti-noise technology.[73] It is to spend 210 million dollars between 1994 and 2000. The program aims at a noise reduction of 10 dB compared with 1992 technology, of which 6 dB should be achieved by new technology relating to the aero-engine. One of the technologies that will be investigated to reach further noise reduction is active noise control. Europe has started a comparable, but smaller, noise abatement research program.[74]

In December 1995, the Committee on Aviation Environmental Protection of the ICAO met to discuss stricter noise rules.[75] About half of the members of the CAEP opposed more stringent noise rules. The arguments they gave related to the earlier mentioned general criteria of the CAEP for issuing noise rules (effects of the measures, technological and economical feasibility). Opponents referred to studies showing that more stringent rules had little or no impact on noise contours around airports. Further, it was argued that while some advances had been made in noise technology, this did not imply room for more stringent norms.[76] More should be known first, for example about the outcomes of the recent NASA noise program.[77] Finally, it was argued that costs for airlines of stricter noise rules would be huge, while the (noise) benefits would be small. According to opponents of more strict noise rules, noise regulation was therefore not economically acceptable.
Proponents of noise rules claimed that the study of the effects of tighter certification rules on airport noise was not representative. More silent technology was or would become available and stricter noise rules would not be too expensive or economically disruptive. Moreover, they claimed that if ICAO failed to issue noise rules this might erode international standardization and ICAO's credibility.
As consensus was required among CAEP's members to propose new noise certification rules, no proposal was made to the ICAO. At this point, the effects of the way in which discussions about noise have become organized in the world of commercial flight become clearly visible. Noise certification is adapted to what is considered technically and economically feasible by conservative estimates.

7.1.3 Transformation of the Technological Regime of Aero-Engines

As a result of the described process of transformation, noise has become an important design criterion in the technological regime of aero-engines. This process started in the late fifties and early sixties. A major reason that noise became an issue by then was that in that time jet aircrafts began to enter service in numbers. These aircrafts were powered by turbojets, which were much more noisy than the earlier propellers. The first measures against aircraft noise were taken by the late sixties and early seventies.
Noise concerns did not result in a major departure from the existing R&D-dependent innovation pattern. They were integrated into the design of new generations of aero-engines. These engines proved to offer good opportunities for noise reduction. Yet,

noise concerns had an important impact on aero-engine and aircraft technology. They were one of the reasons for the failure of super sonic transport (SST) aircrafts like the Concorde in the seventies.[78] In the sixties, SST was often seen as one of the developments of the future, together with the development of vertical and short takeoff and landing (V/STOL) planes. Together with the development and introduction of wide-body aircrafts with high-bypass turbofans, attempts were made to develop and commercialize SST aircrafts. The most important initiative in civil SST was the Concorde. The Concorde was technically achievable, but commercially it was a failure (Box 7.1). Only a few Concordes have been produced and entered service. In the sixties and seventies, the Concorde, and SST in general, did not turn out to be the promise it was thought to be. Not SST aircrafts, but wide-body aircrafts with high-bypass engines became the next generation of aircrafts.

Noise certification and regulation were enabled by the R&D-dependent innovation pattern in the technological regime of aero-engines. Noise research and the development of more silent aero-engines were proactively undertaken by research institutes and aero-engine and aircraft manufacturers in the expectation that sooner or later noise might become an important design criterion. These research and innovative activities enabled actual noise regulation.

The dynamics of expectations that we see at work here is comparable to what we saw in Chapter 4. In that chapter, we saw how in a supplier-dependent innovation pattern, suppliers proactively undertake research and innovative activities that may eventually enable actual regulation. In regimes with an R&D-dependent innovation pattern, proactive R&D activities are undertaken by research institutes and the R&D laboratories of the designer/producers.

Box 7.1 *Super Sonic Flight: the Concorde*

The Concorde was the result of a British-French cooperation, which involved the British Aircraft Cooperation (BAC), Aerospatiale, Rolls Royce and Snecma. Noise was a point of concern in the Concorde project from its departure.

When it became increasingly clear in the mid sixties that international discussions might lead to noise certification, it also became clear that the original goal of the Concorde project to be compatible with the 'noisiest contemporary' aircrafts might be insufficient. Consequently, efforts were undertaken to (further) reduce the noise of the engines of the Concorde, but with little success.

Another problem that the Concorde faced was sonic boom. In several countries, the question was raised whether the Concorde would be allowed to land or overfly territory, while possibly causing sonic booms.Both the noise and the sonic boom problem are closely connected to the high speed at which the Concorde flies. Several solutions to these problems have been proposed, but no feasible solutions without 'excessive' penalties in terms of thrust, costs or fuel consumption could be found.

Noise was not the only problem of the Concorde. It was not even the major one. The most important reason for the eventual failure of the Concorde was its excessive fuel consumption. When the Concorde was conceived, fuel accounted for about 10% of airline operating costs. Due to the 1973 oil crisis and the subsequent rises in oil price, fuel costs rose to about 30% of airline operating costs. (The actual rise in fuel prices was still higher because the modern high-bypass turbofans used about 40% less energy than their predecessors).

Other commercial disadvantages of the Concorde were the relative small number of passengers per flight (resulting in higher direct operating costs), and the fact that the Concorde could not contain enough fuel to make the transatlantic flight in one haul.

Two features of the regime of aero-engines made this regime even somewhat more enabling for the issuing of regulation than the regimes discussed in Chapter 4. First, an important part of the research activities in this regime was, and is, carried out by government financed research institutes. Therefore, governments could influence research priorities in a more direct way than in the technological regimes discussed in Chapter 4. Second, the fact that innovation usually takes place in successive generations meant that noise reduction could be integrated in next-generation designs.

Noise as design criterion goes further than existing noise certification rules. Expectations about future noise requirements play an important role in the technological regimes of aircrafts and aero-engines. Some airlines choose to buy more silent aircrafts (and aero-engines) because of local airport noise rules and noise charges. Given the lifetime of aircrafts, anticipating a future tightening of noise rules is prudent. Aircrafts and aero-engines producing more than 20 dB less noise than current Stage 3 requirements are already in production.[79]
Expectations about noise requirements also play a role in the development of possible next-generation aircrafts like so-called very large aircrafts (VLA) and a possible next generation of SST aircrafts.[80] For both, it is not quite clear which kinds of certification rules will apply. (Super sonic aircrafts, at the moment, have to meet less stringent noise rules than most other aircrafts). Usually, Chapter 3 requirements are taken as minimum requirements for the development of these new types of aircrafts.[81]

While noise has become an important design criterion in the technological regime of aero-engines, this has not solved the aircraft noise problem. Until the mid seventies, the airport noise problem kept growing. According to estimates, in 1975 seven-million people were exposed to 'significant' aircraft noise in the USA.[82] By 1991, this number was claimed to be down to 2.7 million. The FAA has claimed that the US Airport Noise and Capacity Act (ANCA) of 1990 will further reduce the number of people exposed to 'significant' aircraft noise from 2.7 million in 1991 to 400,000 in 2000.[83] Opponents of the ANCA, however, have claimed that the airport noise problem may well grow in the USA because air traffic will continue to grow and the ANCA forbids the issuing of more strict local noise rules.
Whether the noise problem will eventually be solved depends, to an important extent, on how the noise issue is treated within the world of commercial flight. As we have seen, an interaction pattern (regime) in this world has come about which is constraining for the issuing of more strict noise rules. Actors at the local level depend on actors at the international level for the issuing of more strict noise rules. The actors who are active at the international level all have an interest in the long-term viability of aviation and will weigh the effects of noise rules against direct economic impacts and the long-term viability of commercial flight. The way in which noise certification within the ICAO has become organized means that noise certification is adapted to conservative estimates about what is technically feasible and economically acceptable.

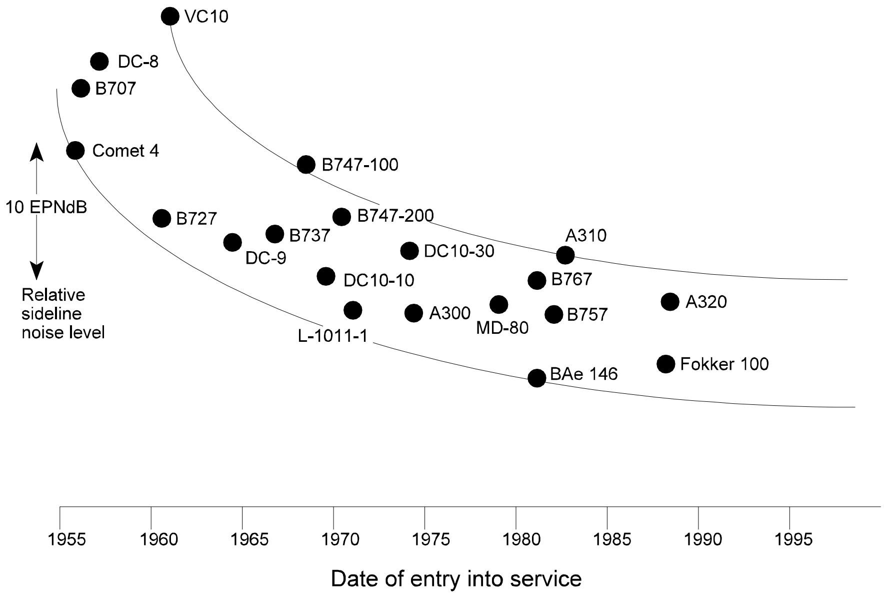


Figure 7.3 *Aircraft Noise Produced by Different Types of Aircrafts*

The noise problem may especially begin to grow again because air traffic keeps growing, while the achievable reduction of individual aircraft noise seems to reach its limits (Figure 7.3).[84] This may reveal a hidden weakness in the way in which the noise problem has been attacked until now. Efforts have focused on making the aero-engines and aircrafts more silent and on operational measures at airports. The growth in air transport has not been attacked. This approach may be characterized as a technological fix because it focuses on technical solutions to a problem that is partly social and institutional in nature. While such a fix partly takes away the noise problem, it may also block social and institutional reforms that eventually may be necessary to solve the aircraft noise problem in the long run. As the commercial failure of the Concorde underlines, too much trust in technological solutions may be contraproductive.

7.2 Safety for the Public; Safe from Public Opinion?

In 1980, David Lilienthal, the first head of the US Atomic Energy Commission (AEC) argued that:

> *Nuclear energy is by no ways finished; it remains one of the great hopes of mankind, and in due course it will play a major role, perhaps the decisive role in providing the energy the world needs so badly. But that goal will not be reached on the road we are now traveling. We need to back away from*

> *our present nuclear state in order to find a better way, a route less hazardous to human health and to the peace of the world and its survival.*[85]

Lilienthal's call was influenced by public doubts about nuclear safety and nuclear

Table 7.1 *Types of Nuclear Reactors*

Nuclear reactors 'burn' fissionable materials, mostly natural or enriched uranium. The fission of uranium produces radioactive atoms, neutrons and heat. The neutrons, in certain circumstances, cause new fission reactions, setting in motion a chain reaction. In so-called thermal reactors a chain reaction only becomes self-sustaining if a moderator is added to slow down the atoms. In breeder reactors no moderator is needed.
The nuclear reaction in the reactor can normally be controlled by so-called control rods. These rods contain materials that catch away neutrons and slow down the nuclear chain reaction. With these rods the nuclear reaction can also be stopped.
The heat generated in the chain reaction is withdrawn by a coolant. This heat is used to boil water and to make steam, which drives a turbine to produce electricity. This conversion from steam into electricity is the same as in conventional coal-, oil- or gas-fired power plants.
Different types of nuclear reactors use different types of fuels, moderators and coolants. The table below summarizes the main types.

Reactor Family	Reactor Types	Fuel	Moderator	Coolant	Initial development
Light water reactor (LWR)	PWR BWR	Enriched uranium	Ordinary water	Ordinary water	USA
Gas-cooled graphite-moderated	Magnox AGR HTGR	Natural or enriched uranium	Graphite	Carbon dioxide or helium	Engeland France
Heavy water reactor (HWR)	CANDU	Natural uranium	Heavy water	Heavy or ordinary water	Canada
Water-cooled graphite-moderated	RBMK	Enriched uranium	Graphite	Ordinary water	Soviet Union
Breeders	LMFB GFBR	Natural uranium or plutonium	-	Liquified natrium or helium	USA

PWR Pressurized Water Reactor
BWR Boiling Water Reactor
AGR Advanced Gas-cooled Reactor
HTGR High Temperature Gas-cooled Reactor
CANDU Canada Deuterium Uranium Reactor
LMFB Liquid-Metal Fast Breeder Reactor
GFBR Gas-cooled Fast Breeder Reactor
RBMK High Power Capacity Channel Boiling Water Reactor (Russian abbreviation)

weapons' proliferation and by a number of problems internal to the regime of nuclear reactors. These problems included public distrust, doubts about safety, licensing problems and poor economic prospects of nuclear reactors.
Lilienthal and others hoped to solve this envelop of problems by developing so-called inherently safe reactors, reactors of which the safety was based on natural laws instead of added safety devices. According to them, this approach would not only enhance the safety of nuclear reactors but also solve the other problems confronting the nuclear reactor technological regime. In the event, they were hardly successful in convincing either nuclear proponents or nuclear opponents of the desirability of this approach. Nevertheless, the striving for inherent safety had some influence on reactor development.
To understand why Lilienthal and others could propose another approach to reactor design, and so become more closely involved in reactor design via a demand, we have to look at the developments inside and outside the regime of nuclear reactors that created room for such proposals. I will do so in Section 7.2.1 and 7.2.2. In doing so, I focus on the USA. Section 7.2.3 discusses proposals for inherently safe nuclear reactors and their reception in the existing technological regime. Finally, I discuss how the striving for inherent safety has influenced actual reactor development, and recapitulate the process of transformation toward inherent safety.

7.2.1 The Light Water Reactor and Growing Problems in the Technological Regime of Nuclear Reactors in the USA

After the Second World War, different kinds of nuclear reactors were developed in different countries (Table 7.1).[86] One reactor type would be especially successful in the USA, and later in other countries: the Light Water Reactor or LWR.[87] This reactor was originally developed for submarine propulsion and inherited its compactness and high power density from this application.[88] In 1957, the first LWR for the generation of energy was built at Shippingporte, greatly enhancing the commercial prospects of the LWR over other nuclear reactor designs. The Shippingporte plant was built as part of the American Atomic Energy Commission (AEC) reactor development program.
In 1963, the Jersey Central Power & Light Company announced the purchase of an LWR on purely economic grounds and without governmental subsidies.[89] It was claimed that this Oyster Creek reactor would soon produce energy cheaper than coal-fired plants.[90] The Oyster Creek plant was delivered by General Electric (GE) on a turnkey contract, which meant that GE was responsible for all cost overruns except of those arising from inflation. The plant was seen by GE as a 'loss leader.' Later contracts had to compensate for this order; the costs of nuclear power plants were believed to decline soon due to growing experience. An important reason for GE to offer this contract was its competition with what would become the other large American vendor of nuclear reactors, Westinghouse. Both companies were eager to take a lead in the nuclear power reactor market.[91]
The Oyster Creek contract was followed by eight other turnkey contracts.[92] These contracts were seen as a proof of the good economic prospects of nuclear power. In

fact, it was commonly believed that the costs of nuclear power would decline due to economies of scale and learning by experience. In 1965, the first nuclear reactors were ordered by utilities without firm price guaranties of the reactor manufacturers. During 1966-1967, a real bandwagon market developed. In these years, utilities placed orders for almost fifty plants. By that time, also two new reactor vendors, Babcock & Wilcox and Combustion Engineering, had entered the market and were intensely competing with GE and Westinghouse.[93]

In all years between 1964 and 1974 the annually ordered nuclear capacity was larger than the total nuclear capacity installed.[94] Also the mean capacity per nuclear plant ordered quickly rose, from about 636 MW in 1963 to 1141 MW in 1972.[95] At no time between 1963 and 1972, any plant in operation was as large as the smallest being ordered.[96] This rapid spread and upscaling of nuclear plants had two consequences.[97] First, there was (relatively) scant operating experience on which the design of new reactors could be based. Second, experience applied to reactors with a smaller capacity than those designed. Operating experience was thus lacking both in quantity and in relevance. This lack of experience would eventually lead to licensing problems for new nuclear reactors, doubts about safety and growing costs for LWRs.

Licensing Problems and Doubts about Safety

In the USA, the AEC was the responsible authority for the licensing of nuclear reactors.[98] In 1947, the AEC established the Reactor Safeguards Committee (RSC), later renamed as the Advisory Committee on Reactor Safeguards (ACRS). This committee played an important role in this licensing process.

Reactor licensing for a long time happened on ad hoc and case-by-case basis.[99] Nevertheless, in the course of time certain general rules crystallized. Until the early fifties, safety of nuclear reactors was to an important extent a matter of siting; reactors had little added safety features. To ensure a degree of safety, they were built in sparsely populated areas far from population centers. This was possible because these early reactors all were test reactors with a small reactor power.

With the commercialization of nuclear power and the desire to build larger reactors with more power, it became virtually impossible to site reactors in sparsely populated areas far away from population centers. The solution was sought in exchanging distance for added safety features.[100] In this approach, safety features were added to a nuclear reactor design based on a review of all ‘credible accidents.’ What counted as an unacceptable ‘credible accident’ was defined by a postulated maximum credible accident (MCA), which was laid down in official regulations in 1962 (10 CFR 100). In the licensing process, it was to be shown that no ‘credible accidents’ were left that would exceed the MCA.[101] Apart from a set of added safety features, nuclear reactors were provided with a containment vessel. This vessel was seen as an independent barrier in case the other safety features might fail.

After 1963, two kinds of licensing problems emerged because of the rapid upscaling and spread of nuclear reactors. The first problem was the deficient capacity of the AEC’s regulatory staff and the ACRS, given the flow of new orders (rapid diffusion) and the innovations in reactor design (rapid upscaling).[102] This problem was not unique to licensing, it also applied to design, manufacture, construction, management and research. The second problem was more fundamental. All kinds of new safety issues were raised by the rapid upscaling of nuclear reactors. Most of these issues reached the agenda of the AEC regulatory staff and the ACRS in relation to the licensing of individual reactors. Some issues were quickly resolved, other stayed on the agenda for a couple of years.[103] In many cases, their resolution led to design changes, added safety features and - sometimes - retrofitting of existing reactors. As a result, ever more safety features were added to nuclear reactors. Eventually, this cumulated in an approach known as 'defense in depth' (see Box 7.2).[104]

The rise of new safety issues contributed to growing (public) doubts about nuclear safety. In 1966, a small revolution in LWR licensing occurred in the USA.[105] This revolution was the result of growing doubts about containment integrity in case of a severe nuclear accident. Especially within the ACRS, it came to be believed that in the case of core melt in larger nuclear reactors - which were then proposed by the reactor manufacturers - the containment could no longer be seen as an *independent* barrier. The ACRS now began to argue for a research program on core melt down and the development of a positive design approach to avert core melt. Officials

Box 7.2 *Defense in Depth*

In the sixties and early seventies, the design of safety systems could be based neither on an adequate theory of reactor operation nor on operating experience. It could not be based on a theory of reactor operation because the physical knowledge of reactor operation was incomplete. It could not, or at least not completely, be based on existing operating experience since this experience applied to reactors smaller than those ordered in the sixties and the beginning of the seventies in the USA. What evolved over time - as a resolution to these problems - was an approach known as 'defense in depth.'
Defense in depth implies three levels of safety, which can be seen as successive design stages in the design of nuclear reactors. These three levels are:

1) *conservative and sound design* with emphasis on quality and reliability. This 'conservative design in detail' was initially based on existing quality standards for, for example, reactor vessels in related industries.

2) *anticipation of the possibility of malfunctioning* by detection and protection systems. These systems are mostly redundant, diversified and physically separated. Redundancy implies that detection and protection systems are designed in two-, three- or fourfold. Diversity means that these redundant systems are not based on the same principles as to avoid common-mode failures. For example, one emergency pump uses electricity from the grid whereas the other uses a stand-by generator. Physical separateness is necessary to avoid that, for example, a fire might destroy all safety systems at once.

3) *added safety design features* based on a set of Design Base Accidents (DBAs). DBAs are sequences of events that lead to a serious accident, like a meltdown of the reactor fuel. In most countries, the reactor vendor has to prove that added design features ensure that a number of DBAs will not lead to a meltdown or another kind of serious accident.
One of the added safety features in an LWR is the *Emergency Core Cooling System (ECCS)* which has to cool down the reactor core in case of, for example, a break in the cooling circuit. Such cooling systems have to be added to an LWR because even if the nuclear chain reaction is stopped immediately after a break in the cooling circuit, the radioactive fission materials continue to produce heat for some time ('decay heat'). Without added cooling systems, the core might melt down.

within the AEC, however, effectively opposed this ACRS proposal. Nevertheless, the growing attention for core melt resulted in important changes in the regulatory process. In the first place, improved quality safeguards were required for the primary steam-circuit of the reactor. Second, emphasis was placed on the so-called Emergency Core Cooling Systems (ECCSs), which were to prevent core melt in case of a Loss Of Coolant Accident (LOCA).

The way the core melt issue entered the licensing process was not unique. Neither was the way it was 'resolved.' Since the fifties, licensing and safety rules were the emergent result of learning and negotiation among the ACRS, the AEC and the reactor vendors.[106] What was special about the core melt issue was that disagreements between the ACRS and the AEC became public and that eventually a public controversy evolved.

This controversy concentrated around the ECCS and started when in 1971 preliminary tests with the ECCS suggested that the system might not be working.[107] The AEC now issued so-called 'interim acceptance criteria' for ECCSs for immediate enforcement. These criteria immediately met opposition from informed nuclear opponents like the Union of Concerned Scientists. As a response, the AEC organized - during 1972 and 1973 - a public 'Rule-Making-Hearing' about the ECCS. Now, the dissatisfaction of the ACRS and the tensions within the AEC became public. Several scientists leaked documents; some of them were fired.

Declining Economic Prospects[108]

Between the mid sixties and the mid seventies, cost estimates for nuclear power became increasingly less optimistic. In 1974, the *estimated* costs of generating nuclear energy were about five times as high as in the mid sixties. In the same time, the estimated time to build a nuclear reactor more than doubled.[109] Nevertheless, nuclear power was still held to be economically competitive in this period, at least by nuclear proponents. That these people saw nuclear power as economically competitive was partly due to the rising costs of electricity generated from fossil fuels. Especially after the oil crisis, the price of fossil fuels rose dramatically. Moreover, many nuclear proponents had the persistent conviction that the costs of nuclear power would eventually fall, or at least stabilize. At the end of the sixties, for example, the reactor vendors admitted that costs had been rising, but they insisted that enhanced learning and economies of scale would reduce costs in the future.[110] In the event, the (estimated) costs of nuclear power stayed rising.

The rising costs of nuclear power were partly due to the earlier discussed safety and regulatory problems. The deficient capacity of the AEC regulatory staff led to longer lead times for building reactors than existing estimates.[111] The arousal of new safety issues led to many design changes. Repeatedly it was discovered that changes in the design and specification of reactors were needed to reach required safety levels. Often, such changes applied to reactors that were already under construction. These changes became an important source of cost overruns.[112]

While utilities believed that cost overruns were mainly due to tighter regulation, lengthy (licensing) procedures, and retrofitting, governmental officials considered poor utility management a main cause of cost overruns.[113] As a matter of fact, some utilities have done much better in making nuclear power economically competitive to fossil fuel than others.[114]

Despite such disagreements, there were at least two points in relation to the economic prospects of nuclear power on which utilities and governmental officials agreed.[115] These were, first, the need to streamline the licensing process and, second, the need to develop standardized reactors. The latter was seen as a means to enhance learning and to simplify the licensing process. It was hoped that by issuing preliminary design approvals for standardized designs, the licensing of individual reactors would be simplified. It was further hoped that the licensing process would be streamlined by the splitting up of the regulatory and promotional/research functions of the AEC in 1974, which led to the foundation of the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC).[116]

Until 1975, it seemed that the oil crisis and the subsequent emphasis on nuclear power in the USA might turn the tide for nuclear energy. However, in 1975 the number of nuclear orders sharply declined. A main reason was that financiers and Public Utility Commissions (PUCs) lost their trust in the nuclear option.[117] Both began to demand utilities to prove the needs for more electricity generating capacity and questioned the economic prospects of nuclear power. In some cases, utilities came in financing problems and were forced to cancel the construction of nuclear plants.

After 1975, ever more reactor orders were canceled and the number of reactor orders quickly fell. Since 1978 no nuclear reactor has been ordered in the USA and the eighties have witnessed the cancellation of nuclear plants in which already substantially was invested.[118]

The 'Failure' of Nuclear Power in the USA

The future of nuclear power proved to be less bright in the USA than it looked for many in the mid sixties. The quick spread of nuclear reactors after 1963 did not result in the expected accumulative innovation and learning process. Experience grew, but costs did not fall. On the contrary, (estimated) costs stayed rising and so did doubts about the safety of nuclear reactors. What was set in motion, then, was a cumulative process in which cost overruns, licensing problems, doubts about safety and eventually public distrust reinforced each other.

Before I discuss public protests in more detail, it is useful to spend some words on why nuclear energy came in trouble in the USA and why it did so, even independent from public doubts. Much has been written on this subject and it is not my intention to add to this debate. I will only highlight some aspects that are useful for understanding the case study and that reveal peculiarities of technological regimes with an R&D-dependent innovation pattern.

A first reason that nuclear energy came in trouble in the USA is the early and, with hindsight, rather uncritical choice for the Light Water Reactor. Bupp & Derian (1978) describe how in the USA a self-sustaining process was set in motion in which governmental officials, utilities and reactors vendors cited each other's expectations and promises about LWR technology.[119] One reason that the technological promise of the LWR became shared so quickly by so many in the nuclear reactor regime were the competitive relations between the parties involved. GE and Westinghouse both wanted to take the lead in the nuclear reactor market and, therefore, presented optimistic expectations about the prospects of the LWR. Some utilities choosing for nuclear power were motivated by the fear to be squeezed out of business by new (publicly managed) companies.[120]

The acceptance of the LWR as technological promise resulted in a lock-in.[121] The LWR was not a superior technology, but was chosen because of the competitive advantages it gained during its early development and adoption. Due to choices made during these early development stages, the LWR had several disadvantages, in particular in relation to safety. Especially the high power density of the LWR, inherited from the submarine project, is a safety disadvantage because it makes the reactor more difficult to control in case of an accident.[122]

Still, many scientists, research institutes and government agencies in the nuclear reactor regime did not conceive the LWR as the most desirable option for the future.[123] LWRs were seen as wasteful of nuclear fuel. Sooner or later, they would be plagued by a shortage of nuclear fuel, it was believed. Moreover, LWRs operated at a relatively low temperature, which made them thermodynamically not the most efficient type of reactor. Therefore, scientists and researchers envisaged a presumptive anomaly with respect to the LWR. An anomaly that could be solved, they presumed, by another type of reactor: the breeder.

In the mid sixties, the AEC decided to concentrate its development efforts on the breeder reactor.[124] Meanwhile the AEC withdrew resources for (safety) research on the LWR because it believed that the refinement of the LWR design and the resolution of safety issues was to be carried out by industry itself. In the eyes of the AEC, and many researchers, the principal technical problems of the LWR had been resolved.

Looking back, the AEC and the nuclear reactor vendors underestimated the engineering problems related to the upscaling of the LWR. They focused on making the LWR, and nuclear reactors in general, technically optimal, neglecting the efforts required to make nuclear energy also an economically and socially viable option. This attitude has been described as technological enthusiasm:

> *[T]echnological enthusiasm allowed grave problems to be treated lightly or ignored completely. If problems were recognized at all, enthusiasts assumed that solutions would be found during the constant march of technical progress. That seemed a reasonable assumption, even though it was paraded as fact.*
>
> *The first weakness of the American program was . . . the rapidity with which it was put in place after 1963. There were significant development and dissemination costs that enthusiasts had pretended would not be there. [. . .]*
>
> *Technological enthusiasm also allowed utilities to overlook the real managerial challenges of nuclear energy. Just as they assumed that technical problems were solved, they assumed that they could operate nuclear reactors just like fossil fuel plants. [. . .]*
>
> *Third, utility financing was not assured. [. . .]*

Finally, the agency that should have brought the utilities out of their naïveté, the AEC, had abdicated this function. It had shifted its internal focus to breeder research on the enthusiastic assumption that the major LWR problems had either be solved or would be solved by industry.[125]

Technological enthusiasm was encouraged by the existing R&D-dependent innovation pattern in the regime of nuclear reactors. For scientists and researchers, who play an innovative rather than a supportive role with respect to technological development in regimes with an R&D-dependent innovation pattern, focusing on the next generation of nuclear reactors, the breeder, was natural. For them and for many engineers employed by the reactor vendors and the utilities, nuclear energy mainly appeared as a technical challenge.[126] This is not quite surprising for a regime with an R&D-dependent innovation pattern, because in such a pattern innovations usually start as technological promises, to be aligned later to functions. It was this alignment, with the function of cheap and safe power, that could not be brought about in the technological regime of nuclear reactors in the USA, at least not in a robust way. The failure to do so resulted in aggression of the existing regime toward its environment. This aggression was made manifest by public protests.

7.2.2 Public Protests Against Nuclear Energy[127]

In the USA, the sixties had witnessed some public protests against nuclear power plants but these protests were mostly local. The object of protest was often 'thermal pollution.' Nuclear reactors released a relatively large amount of hot 'cooling water' into the environment.[128] In the mid sixties, this hot water was commonly dispersed into rivers, lakes or the ocean. Since this hot water can affect aquatic life, the dispersion of cooling water became a serious concern of environmentalists and, sometimes, of commercial fisheries.

In 1971, environmental protesters achieved an important victory. A federal court ordered major revisions in the AEC Environmental Impact Statement (EIS) for a planned reactor at Calvert Cliffs. The licensing process came to a standstill for 18 months. Moreover, the AEC had to revise the licensing process for all reactors as to include more encompassing EISs. This led to longer licensing times for nuclear reactors.[129]

In the early seventies, the earlier discussed ECCS controversy added two new elements to nuclear protests. First, nuclear safety became an important focus for anti-nuclear protests. Second, several scientists came to play an important role in the growing nuclear protests. Dissident scientists resigned from or fired by the AEC and other critical scientists played an important role in organizations like the Union of Concerned Scientists.

In both the USA and Europe, the anti-nuclear movement became a national and very visible movement in the mid seventies.[130] Anti-nuclear protests by then not only concerned safety issues but also nuclear waste disposal and the fear of proliferation of nuclear arms. Increasingly, the protesters connected nuclear power with the neglect of a range of generally held societal and political values. The 'atomic state' was portrayed as a police state, especially in Robert Jungk's book *der Atom-Staat*. The unwillingness of the authorities to ban nuclear power or listen to the protesters was seen as typical for the modern authoritarian state not willing to listen to its citizens. The anti-nuclear movement increasingly developed a broad ideology not only concerning nuclear technology and its consequences but also expressing the fear of ecological devastation and the conviction that western society was facing a serious crisis.

So, for many members of the anti-nuclear movement, especially those radical environmentalists, leftists and the (former) members of the student movement, the movement became a way to express and possibly reach their political and ecological ideals. Consequently, the anti-nuclear movement had a strong moralistic tone. In the ears of the pro-nuclear bureaucrats and industrialists, however, it was just an irrational sound, voicing groundless fear. Most of the pro-nuclear bureaucrats and politicians were convinced that they were serving if not humankind then at least their national state. For many of them, nuclear energy was the route to national energy independence and international competitiveness. In the eyes of the nuclear movement, on the other hand, these people were only serving their own interests and those of industry. Both parties then were convinced that they were serving important social values neglected by the other.

In 1975 Germany witnessed a massive nuclear site occupation at Whyl that lasted almost a year. Construction of the atomic plant stopped in March 1975 due to a court decision. The utilities appealed against this decision. In January 1976, the authorities promised to consider the evidence provided by the citizens on the nuclear power plant and guaranteed that construction would not restart until the final court decision. The protesters then left the site. In March 1977, the court decided to ban construction on the basis of a single technical point.

The Whyl site occupation encouraged nuclear protests in Europe and in the USA. Around the summer of 1976, the American and French movement also began to organize site occupations. In Germany, however, the Whyl experience made the authorities unwilling to accept another site occupation. When thousands of protesters tried to occupy the Brokdorf site in Germany in 1976, it led to a violent confrontation with the police in which hundreds of people were wounded. This violent confrontation threatened the public confidence in anti-nuclear groups. Since then especially European anti-nuclear groups - which were never really one unity - have diversified their tactics and means. Participation in elections and contesting decisions in the courts became more common strategies.

Such strategic detours have sometimes been successful. In Germany, nuclear opponents succeeded in banning several plants by court decisions. In other countries the success of the anti-nuclear movement has not been that direct. In fact, the effects of nuclear protests have differed significantly from country to country. Nevertheless in many Western countries, nuclear power has become a political issue, concerning not only the nuclear specialists of the political parties but all politicians.[131] In some countries, the growing political character of nuclear energy led some political parties to taking an anti-nuclear stance and governments to holding referenda on nuclear

power. In 1978, for example, the Austrian nuclear power program was banned in a referendum. Sweden voted to phase out nuclear energy in a referendum in 1980. Also in countries where no political decision was taking to ban nuclear power, nuclear protests had an important effect. The success of the protests shifted the burden of proof on issues like nuclear safety from opponents to proponents of nuclear power.[132] Where in earlier time nuclear protesters had to prove that nuclear safety was something to bother about, now nuclear proponents had to prove that is was something *not* to bother about.
Another important effect of nuclear protests, especially in the USA, was a further rise of the costs of nuclear power.[133] Cost additions had three sources.[134] First, nuclear protesters often succeeded in slowing down licensing and construction processes. Second, doubts about nuclear safety led to tighter safety regulations and some retrofitting of existing reactors. Third, political and court decisions provoked by nuclear opponents added to the complexity of licensing and other procedures.

In the USA, public opinion polls for the first time showed a majority against nuclear power after the Three Miles Island nuclear reactor accident in March 1979.[135] The accident did not cause a halt in nuclear plant orders because these had already stopped a year before. The Three Miles Island accident and the nuclear protests in general meant that the nuclear proponents had to solve another problem to revive the nuclear option in the USA: they had to convince the public.

7.2.3 Inherent Safety

The growing internal problems and nuclear protests sketched in the preceding sections created a climate in which maverick nuclear researchers could become involved via a demand. These researchers advocated a new approach to nuclear safety: developing nuclear reactors that are more inherently safe by design. They claimed that this approach would help to solve the problem in which nuclear power had come.
The striving for inherent safety originated in two countries in which nuclear power was in serious problems: Sweden and the USA. In Sweden, the reactor vendor ASEA Atom (now ABB) in 1979 decided to go back to the basic principles of reactor design to design an LWR without the need of active safety systems or human intervention.[136] Probably, it was hoped that such a reactor design would forestall public doubts and a national moratorium on nuclear energy. (Sweden voted to phase out nuclear energy in a referendum in 1980.) In the USA, discussions on inherent safety were mainly started by nuclear researchers. They conceived inherent safety as a solution to an envelope of problems like public doubts, licensing problems and cost overruns. I focus on the developments in the USA.

The Striving for Inherent Safety in the USA

One of the first and most influential people in the USA to argue for another approach to the safety of nuclear reactors was David Lilienthal in his 1980 book *Atomic Energy; A New Start*.[137] In this book, the first head of the AEC argued that 'we' were on the wrong way toward nuclear safety. According to Lilienthal the nuclear industry had concentrated its efforts on the LWR too early: 'Today the light water reactor, with its dangerous side effects, is virtually the only nuclear generation facility available to the nuclear industry.'[138] Old alternatives to the LWR should be reconsidered and new alternatives should be developed. These alternatives might offer 'greater safety and certainly far less complexity.'[139] Initially, Lilienthal's proposal merely met scepticism.[140] Nevertheless, the Institute of Energy Analysis of the Oak Ridge Associated Universities (IEA) organized a workshop on the practicability of an inherently safe nuclear reactor in May 1980. 'A dozen old-timers who had been responsible for setting nuclear energy on its main technical paths'[141] met. They came to the conclusion that it would be wise to seriously study the prospects for inherently safe nuclear reactors. They also concluded that the safety of existing LWRs should first be assessed. Most of the participants believed that these reactors were already safe enough.[142]

In 1981, the Mellon Foundation decided to support a two-year study at the IEA 'to investigate technological approaches that might restore the confidence in nuclear power that had been shattered by the Three Miles Island accident.'[143] This study resulted in the 1985 volume *The Second Nuclear Era; A New Start for Nuclear Power*. In this book IEA director Weinberg and his colleagues stated that 'the improvements in LWRs have been impressive - so impressive, we believe, that nuclear power, compared with other risks, is very safe.'[144] While inherently safe nuclear reactors were not considered immediate necessary for safety reasons, Weinberg and colleagues maintained that they should be developed to help solve a number of safety-related problems, *i.e.* declining public acceptance, increasing costs and licensing uncertainty. As they stated it:

> *[W]e made an underlying assumption that the frustrations over regulation, mounting costs of reactors, and public disaffection with nuclear power are, in the final analysis, traceable to concern over the 15 billion curies of radioactivity contained in a 1,000-megawatt LWR. The radioactivity cannot be eliminated. But if one could design a reactor that would make a TMI-2-like incident [the accident at Three Miles Island, IvdP] essentially impossible, much of the current regulatory system would be superfluous, the public's aversion to nuclear energy would be reduced, and, insofar as such concerns ultimately are reflected in high cost and risk, utilities would regain their interest in nuclear power.*[145]

Weinberg and colleagues furthermore argued that inherently safe reactors, demanding less competence of operators, would make nuclear energy a more feasible option for countries with no experience in the nuclear field. Moreover, they argued that while current LWRs and LWRs under development are safe enough in today's 500-reactor world, because they amount to a total core melt probability of once in the 20 years or lower, they might not be safe enough in a world of much more than 500 reactors.[146] So, in the future inherently safe reactors might also be necessary for safety reasons.

According to the IEA researchers, inherently safe reactors differ from existing reactors in the sense that they are not based on active safety systems added to LWRs or other types of reactors, but on natural laws:

> *[I]nherently safe reactors are safe not because of the intervention of active systems, which always have some probability of failure, but because of the working of immutable laws of thermodynamics, of gravity, and of nuclear physics. The trick is to choose reactor configurations that embody such immutable principles.*[147]

Inherent safety is defined as the absence of the need for human intervention, external energy supply or moving parts (pumps) in the operation of safety systems. This type of safety assurance is often also described as *passive safety*. The *Second Nuclear Era* suggests that inherently safe nuclear reactors are resistant to even the most unlikely events:

> *We must concede that we adopted the stance that certain threats - acts of war, earthquakes beyond a certain size, sabotage, acts of terrorism - are too farfetched to be considered in current design standards. Yet, unlikely though they may be, we recognize that such events cannot be considered totally irrelevant, because a Second Nuclear Era might last for a long time - events that on a short time scale may be regarded as too unlikely to occur might be worthy of attention on a scale of hundreds of years. In the long run, then, although current LWRs are relatively safe, it would make sense to have a totally "forgiving" reactor that is resistant to these very unlikely threats.*[148]

This quotation suggests that inherent safety is nearly equivalent to absolute safety. However, in another 1985 publication, Weinberg and a colleague have suggested that some events may cause an accident in an inherently safe nuclear reactor. As they stated it there:

> *In some sense there is no such thing as a totally safe reactor. Some events with probabilities of, say, 10^{-9} per reactor year (RY), that could damage even the most inherently safe reactor can probably always be conceived. One can argue that, ultimately, one relies on a PRA [Probabilistic Risk Assessment, IvdP], albeit a very far-fetched one, for ensuring safety. Thus one can hardly avoid answering the question, "How safe is safe enough?", even with inherently safe reactors. However . . . some of the advanced actively safe reactors yield PRA estimates of core melt in the range of 10^{-7}/RY, and passively safe reactors yield PRA estimates of 10^{-8}/RY - 1000-10,000 times lower than the safety goals promulgated by the NRC. Reactors with such low CMPs [Core Melt Probabilities, IvdP] ought to be regarded as meeting Lilienthal's call for a safe reactor.*[149]

According to this quotation, inherent safety is not and cannot be equivalent to absolute safety. Indeed, recently Weinberg has defined 'inherent safety' as equivalent to passive safety and implying a CMP in the range of a probability of once in the 10^9 years.[150]

The quotation also suggests that 'inherent safety' is just one of the means to enhance the safety of nuclear reactors and that other means can be applied too. While several nuclear proponents have indeed made this point, for Weinberg and colleagues inherent safety is more than just a means to enhance safety. They conceive it as new guiding principle for nuclear reactor design that will help to solve an envelope of problems facing nuclear energy. This new guiding principle implies a new design approach: not starting with a reactor concept like the LWR and then adding safety systems but starting with inherent safety and then selecting the reactor best able to realize this concept.

Support for Inherent Safety?

Around the same time as the publication of *The Second Nuclear Era*, two other important American reports appeared on 'the future of nuclear reactor development in the USA.' These were a 1984 report by the Congressional Office of Technology Assessment (OTA) named *Nuclear Power in an Age of Uncertainty* and the 1985 report *National Strategies for Nuclear Power Reactor Development* published by MIT (Massachusetts Institute of Technology).[151] In contrast to *The Second Nuclear Era* that strongly focused on the inherently safe reactor as technological fix, these studies also stressed institutional reforms. Moreover, both studies considered advanced LWRs a possible route to the revival of nuclear energy in the United States.[152] Nevertheless, both favored in one way or another the development of possibly inherently safe reactors.

In the eighties, in such journals as *Nuclear Safety, Annals of Nuclear Energy, Annual Review of Energy, Science, the Scientific American* and *Issues in Science and Technology*, articles appeared that advocated the striving for inherent safety.[153] In most of these articles the same types of arguments have been put forward in favor of inherently safe nuclear reactors.[154] Existent reactor types, mainly LWRs, are in principle safe enough, but their safety is based on active systems. Because of more stringent licensing policy and safety requirements ever more safety systems have been added, making existing reactors highly complex. This complexity has led to rising costs, licensing uncertainty and may have introduced new safety hazards due to unknown interrelations between different safety systems. Moreover, the safety analysis of these types of reactors, which is based on complex probabilistic risk assessments (PRAs), is hard to grasp for the public. Therefore nuclear reactors should be passively or inherently safe, based on transparent and simple safety systems that can be understood by the public.[155] So, for proponents of inherent safety, the guiding principle 'inherent safety' implies several things like passive safety systems, transparency, simplicity and ruggedness.[156]

The early proponents of inherent safety have been described as a group of maverick technologists, 'slightly outside the mainstream of the nuclear power industry.'[157] Nevertheless, they included well-known nuclear researchers like Alvin Weinberg,

(former) director of the Oak Ridge National Laboratories (ORNL) and Lawrence Lidsky, professor of nuclear engineering at MIT. Support from outside the research community for the inherent safety movement has been limited.[158]
The reaction of the US government to the striving toward inherent safety has been 'cautious.' Nevertheless, NRC and the US Department of Energy have undertaken some small initiatives in favor of inherent safety, like a design competition. Some politicians have also supported the striving for inherent safety, especially after the Chernobyl accident in 1986. In 1986, Soviet Secretary Gorbachev sent a letter to Hans Blix, Secretary-General of the IAEA (International Atomic Energy Agency) to ask for an international program for the development of a new generation of safe nuclear reactors. In 1988, Michael Dukakis, the Democratic candidate running for the US president election expressed his opposition against nuclear power until a new safer generation was developed. In the American Congress, there are some advocates of inherent safety. However, inherent safety is by no means an official goal of US politics with respect to nuclear energy.
Most of the reactor industry has been skeptical about the striving for inherent safety. Already in 1984 the US Atomic Industrial Forum stated:

> *Increasing discussions in recent months, presumably as a result of the accident at Three Miles Island, have been directed at the rhetorical question of whether renewed utilization of the nuclear option should not be*

Table 7.2 *Conflicting Views on Problems Facing Nuclear Reactor Regime*

Inherent Safety Advocates		*Institutional Reform Advocates*
Inherent safety, implying a radical departure from existing technology (LWRs)	*Enhancement of Safety*	Advanced active and passive safety to be developed in a step-by-step approach
Transparent and enhanced safety will restore public confidence	*Restoration of Public Acceptance*	Public acceptance is either ineradicable or will be resolved by such developments as growing electricity demands, the need to curb CO_2 emissions and lower prices of nuclear generated electricity.
Enhanced and transparent safety based on less complex passive systems will ease licensing process and resolve licensing problems	*Licensing Problems*	Regulatory reforms needed. Extended standardization of nuclear plant will quicken licensing procedures.
Inherently safe, less complex safety systems will make nuclear reactors cheaper. Economic prospects will be improved by shorter licensing procedures and growing public acceptance	*Poor Economic Prospects*	Standardization will reduce costs. Improved operation of nuclear plants needed. Gradual improvement of existing technology

based on some system other than the light water reactor (LWR). The discussions, however, have failed to acknowledge the extensive research, development and demonstration effort that went into alternative systems in the late 50s and early 60s. They have failed to recall the deliberate reasoning that went into the selection of the LWR, not only in the USA but subsequently in Europe and the Far East. They have failed to recognize the improvements that have been incorporated into the LWR as a result of 25 years of design and operating experience, including the improvements made since the accidents at Three Miles Island. And finally, they have failed to specify how they consider the LWR system to be flawed or why alternative systems could be expected to perform any better.[159]

As this quotation shows, most of the nuclear industry has distrusted the striving for inherent safety: existing reactors are already safe enough. Moreover, for the reactor vendors the development of inherently safe reactors may compete with their existing designs. Nevertheless, a number of reactor vendors have developed design concepts for inherently safe reactors, as we will see in Section 7.2.4.
The utilities as well, at least in the United States, have felt little need to ask the reactors vendors for inherently safe designs. They need reactors that are not only safe but also reliable and cost-effective. While proponents of inherently safe reactors in their argumentation clearly have anticipated these kinds of considerations, they do not seem to have convinced the US utilities. Especially since their experience with costs-overruns, poor operation and growing licensing problems in the sixties and seventies, most utilities are reluctant to apply radical new types of nuclear reactors that may imply serious risks in relation to costs, licensing procedures, development, construction time, and even safety.

The resistance to inherent safety seems to go deeper than the reasons outlined above. According to the opponents of inherent safety, the roots of the problems in the technological regime of nuclear reactors are not technological but institutional. Not the design of nuclear reactors should be blamed, but the lack of public confidence and the lengthiness of licensing procedures.[160] They believe that public distrust will either be ineradicable or be resolved by such developments as growing electricity demands, the need to curb CO_2 emissions due to the greenhouse effect and lower prices of nuclear generated electricity. While they recognize that nuclear energy faces several - economical, regulatory and political - problems, they think that inherently safe reactors will not solve these problems.
The debate, then, boils down to the strategic question how to overcome the problems the nuclear reactor regime is now facing: public distrusts, doubts about safety, lengthy and complex licensing and poor economic prospects. As an inherent safety proponent has noted:

The debate can be summarized in a fundamental strategic question: Which is more likely to be effective -an attempt to restructure political, industrial and regulatory institutions to accommodate the special demands of present *technology, or an effort to tailor the technology to the capabilities, limitations and needs of the institutions that now exist?*[161]

Opponents of inherent safety and sceptics have mainly stressed the need for institutional reforms, like regulatory reforms and the use of more standardized technology.[162] Proponents of inherent safety do not reject these reforms, but they believe that such reforms are not enough to solve the problems nuclear energy is facing in the USA.

The opponents of inherent safety further believe that inherent safety is still an unproven concept, implying serious economical and regulatory risks. In their eyes, the promotion of inherent safety may convince the public that the existing reactors are not safe enough.[163] Enhanced safety should therefore be sought in a step-by-step approach building on existing designs. In the end, this step-by-step approach may lead to reactors that embody some of the principles argued for by the inherent safety proponents, but this is no necessity. The conflicting views of proponents and opponents are summarized in Table 7.2. Box 7.3 briefly summarizes the discussion on inherent safety in Europe, in particular in the Netherlands.[164]

Box 7.3 *Inherent Safety in Europe*

Outside the USA, the discussion on inherent safety did not capture very much attention until the Chernobyl accident in 1986. After the accident, European experts argued that ‘it could not happen here.’ While they had good technical arguments why *this* type of accident could not happen in western nuclear plants, they could not convincingly argue that severe accidents were ultimately impossible. For many, the Chernobyl accident proved that Pennsylvania - the US State where the Three Miles Island accident had happened - was indeed everywhere, as nuclear protesters had shouted at the end of the seventies. In Germany, the Chernobyl accident led to heated demonstrations against nuclear power. In countries like the Netherlands and Great Britain the accident came at an unfortunate moment for nuclear proponents. Both countries were making plans to enlarge their nuclear capacity and faced coming elections when the accident happened. In both countries these plans have been delayed, in the Netherlands completely, in Great Britain partly.

In the Netherlands, there has been some discussion about inherent safety after the Chernobyl accident. Initially discussions merely took place between technical experts. Most experts presented inherent safety in the first place as a new means and philosophy to enhance safety. Secondly and often only implicitly, inherent safety was presented as a possible means to make nuclear energy politically more acceptable. Discussions on the costs and licensing of nuclear power did not play a large role in the Netherlands, probably because the Netherlands has only two nuclear reactors of which the last started operating in 1973. However for a resurrection of nuclear energy it was - contrary to the USA where individual utilities decide to build nuclear reactors - important to convince parliament. In 1993 the specialist of the Dutch Labor Party urged the development of inherently safe reactors. Other political parties, however, have been skeptical about inherent safety. It is doubted whether inherently safe designs will be any safer than (other) advanced LWR designs. Moreover, proponents of nuclear energy tend to see the striving for inherent safety as a tactical move to delay the building of new nuclear plants. (It will probably take twenty years or more to design and build an inherently safe nuclear reactor.)

Table 7.3 *Safety Definitions Given in TECDOC*-626

Inherent safety	The elimination of a threat by the choice of materials or design.
Passive safety	The functioning of a component without external input. (Four categories of passive safety are specified).
Active safety	Every safety component that does not fall in one of the earlier categories is actively safe.
Transparent safety	Safety ensured in a way that can be understood by outsiders.

Discussion About the Term 'Inherent Safety'[165]

Since the term 'inherent safety' was introduced, its use has not been without ambiguity. Weinberg defined inherent safety, as we have seen before, as a very small probability of an accident. For him, the term concerned the whole plant and implied transparent safety and a new safety philosophy. Other nuclear proponents have come to use the term 'inherent safety' to refer to all kinds of advanced reactors. These people reject inherent safety as a new guiding principle. For them inherent safety simply means enhanced safety and that goal can be reached in several ways. In their view, all advanced reactors may be called inherently safe. Environmental and anti-nuclear groups, on the other hand, have either rejected the striving for inherent safety or required the term to mean absolute safety. Finally, some people, opponents as well as proponents of nuclear power, have rejected the term because it suggests more - absolute safety - than can be made true.

The unclearness of the term 'inherent safety' drew the attention of the IAEA in 1988. To establish a common and consistent definition of 'inherent safety,' the IAEA initiated a discussion within the international nuclear regime. This discussion resulted in the 1991 document TECDOC-626 of the IAEA. In this document the IAEA defined terms like 'inherent safety,' 'passive safety,' 'active safety' and 'transparent safety' (see Table 7.3). Most important, inherent safety is defined as a characteristic of components of nuclear reactors in this document. This implies that speaking about an inherently safe nuclear reactor or plant is impossible since only components can be inherently safe. So, the IAEA definition undermined one of the main goals of the inherent safety advocates: another approach (philosophy) to the safety of nuclear reactors as a whole. As such, it may be interpreted as a move of regime insiders to redefine the striving for inherent safety to fit it into the existing regime.

7.2.4 Development of Inherently Safe Reactors

In what ways have the discussions on inherent safety affected actual reactor development? In the mid eighties, the prospects for the development of inherently safe reactors looked promising. *The Second Nuclear Era* had identified two types of

inherently safe reactors that were under development: the PIUS (Process Inherent Ultimately Safe) reactor and the MHTGR (Modular High Temperature Gas-cooled Reactor). The working of these reactors is briefly explained in Box 7.4.[166] According to the *Second Nuclear Area* further development and testing of these reactors should be undertaken.
In a report of MIT that appeared in 1985, the PIUS and MHTGR were recognized as long-term options, in case advanced LWRs would not regain support from utilities and the public.[167] The MIT Report stressed that such a choice implied a major break with the existing policy, which was based on the breeder reactor as long-term option. As the MIT Report stated:

> *A fundamental change in national policy priorities guiding advanced reactor development efforts is recommended. Previously, the main public policy objective was to develop breeder reactors in preparation for the time when uranium depletion and price escalation rendered light water reactor systems uneconomic. For at least the next decade, the main concern should*

Box 7.4 *Inherently Safe Nuclear Reactor Designs*

The two most important existing alleged inherently safe reactor designs are the PIUS (Process Inherent Ultimately Safe) reactor and the MHTGR (Modular High Temperature Gas-cooled Reactor).

The *PIUS* is an LWR of the pressurized water type. According to its designers, it operates safely without reliance on active safety systems or operator action. This is achieved by submerging the entire core of the reactor in a pool of borated water. This pool is hydraulically connected with the primary cooling system. Under normal circumstances, the pressure developed by the coolant pumps prevents the water from entering the core. In case of an accident, the pool of borated water will flood the core due to natural convection. The water then cools down the core; the boron in the water absorbs the neutrons, slowing down and eventually stopping the nuclear reaction.

The *MHTGR* is a descendant of the gas-cooled reactors in operation. A common safety advantage of gas-cooled reactors is that they have a lower density than LWRs. This diminishes the effects of decay heat and so the risk of a core melt in case of a severe accident.
A main difference between the MHTGR and existing gas-cooled reactors is that the MHTGR consists of several smaller modules. It is claimed that this feature makes superfluous some added safety systems.
At least two types of MHTGRs have been under development, one in the USA and one in Europe. Both use fuel particles, which are coated with silicon carbide and carbon, and are embedded in fuel elements. The ‘European’ reactor has a pebbled bed core, which can be refueled during operation. The fuel elements of both types of reactors are claimed to be able to withstand temperatures up to 1600 ºC. The large surface to volume ratio of the fuel elements should ensure that the reactor temperature cannot reach this 1600 ºC, even if the reactor would lose all of its coolant.

When the earlier mentioned IAEA definition is strictly interpreted, it is doubtful whether designs like the PIUS reactor and the MHTGR can be seen as inherently safe because they do not *eliminate* all possible threats. (Elimination of threats is not the same as taking preventives for the case such threats might happen). The inherent safety of PIUS reactor, moreover, is based on the movement (input) of water which makes the design according to a strict interpretation of the IAEA definition even not completely passively safe.

be to prepare for the possibility that U.S. utilities will not regain confidence in conventional LWR technology. The primary goal should be the development of innovative nuclear power plant systems which would compete more effectively with coal. ... Left to itself, private industry will almost certainly fall short of the societal optimal level of effort in this area. The technical emphasis should be on the development of small to medium-sized reactors fundamentally different from conventional LWR designs, relying to the maximum extent on passive safety features, and designed to minimize on-site construction requirements.[168]

This recommendation implied federal funding for the further development and testing of the PIUS reactor or an MHTGR.[169]

Reactor vendors and research institutes all over the world are now developing and testing several advanced reactor designs, including claimed inherently safe reactors like the PIUS and MHTGR. The major reactor designs now under development are summarized in Table 7.4.[170] Most of these designs are developed by a major reactor vendor (GE, Westinghouse, ABB/Combustion Engineering, Siemens, Framatome) in cooperation with research institutes from different countries and smaller (supplying) firms.

As Table 7.4 shows, most development efforts concentrate on conventional LWRs. The idea, which existed in the sixties, that the LWR would soon be replaced by more efficient reactors like the breeder is not very prominent anymore. While the breeder is still seen as a possible long-term option, most reactor vendors and utilities prefer a step-by-step development taking the existing LWR as point of departure.[171]

Reactor vendors and utilities aim at an innovation pattern in which new reactor designs follow each other in successive generations. As Table 7.4 shows, reactor designs that are now under development may be categorized as first, second and third generation design. The first two generations apply in particular to so-called advanced LWRs.

Typical reactors of the so-called first generation of advanced LWRs have a capacity of 1300-1500 MW. The safety of these reactors is based on active safety systems. They fit into the historical trend of growing reactor capacity and added active safety systems. Several of these reactor designs, like the System 80+ and the ABWR, have been approved by the NRC in the USA.[172]

The proposed second generation of LWR designs has a capacity of about 600 MW. These reactors incorporate passive safety features.[173] In both respects, the designs depart from the historical trend in reactor development. One of the designs is the AP600 of Westinghouse. NRC safety approval for this reactor is expected in 1997.[174] General Electric, on the other hand, has decided in January 1996 to abandon its development efforts on its second generation design, the SBWR. According to GE, cuts in US federal subsidies for reactor development did not make it prudent any longer to invest in the development of this reactor.[175]

The two major types of inherently safe third generation reactor designs that are under development are the PIUS and the MHTGR. Work on the PIUS reactor started in 1979 by ASEA Atom (now ABB) in view of the Swedish moratorium on nuclear power.[176] Since 1985, also other companies and research institutes have investigated

the PIUS design and carried out tests. This includes companies and research institutes from Italy, South Korea, China and Japan. Also, a boiling water variant of the PIUS has been developed. Further development, testing and eventually licensing will take several years.
MHTGRs have been developed by General Atomics in the USA and by Siemens and ABB in Europe. Test plants have been built in both the USA and Europe.[177] Corporations and government agencies from various countries have been involved in research and testing efforts with respect to the MHTGR. The commercial prospects of the modular high temperature gas-cooled reactor are uncertain. Reactor vendors are not completely convinced that participating in MHTGR development programs is prudent, even whether governments and governmental agencies bear a large part of the costs. Siemens, for example, in 1993 decided to abandon its efforts with respect to gas-cooled reactors, after having been active in this field for two decades.[178]

Whether the reactor vendors will actually bring (alleged) inherently safe reactors onto the market depends on two factors: the expected demand for these reactors and the willingness of governments and governmental research institutes to subsidize or participate in development programs. As the earlier mentioned decisions of General Electric and Siemens underline, it is doubtful whether third, and even second generation designs will be further developed if no governmental support is available. With respect to the latter, it is significant that the research climate for inherently safe nuclear reactors seems to be worsening, at least in the USA. In 1992, the Committee on Future Nuclear Power Development under the Energy Engineering Board of the National Research Council published a report with the title *Nuclear Power; Technical and Institutional Options for the Future.* The report was the result of a US congressional request in 1989 to let the National Academy of Sciences conduct ‘ ... a critical comparative analysis ... of the practical technological and institutional options for future nuclear power development and for the formulation of coherent policy alternatives to guide the Nation’s nuclear power development.’[179] The report assessed several advanced, passively and inherently safe (first, second and third generation) reactor designs and concluded:

> *The Committee could not make any meaningful comparison of the relative safety of the various advanced reactor designs. The Committee believes that each of the concepts considered can be designed and operated to meet or closely approach the safety objectives currently proposed for future advanced LWRs. The different advanced reactor designs employ different mixes of active and passive safety features. The Committee believes that there currently is no single optimal approach to improved safety. Dependence on passive safety features does not, of itself, ensure greater safety. The Committee believes that a prudent course retains the historical defense-in-depth approach.*[180]

The Committee did not believe reactor designs like the PIUS and the MHTGR to be safer than advanced actively safe reactors. It thought reactor designs like PIUS and the MHTGR to take at least twenty years to be developed for commercial use.

Table 7.4 *Next-generation Reactors under Development or Study*

Reactor Family	'First' generation designs	'Second' generation designs	Alleged inherently safe designs or 'third' generation designs
Light Water Reactor (LWR)	Advanced Actively Safe LWRs: APWR (Westinghouse/Misubushi) ABWR (General Electric, Hi, To) BWR 90 (ABB) System 80+ (CE); EPR (NPI) SWR 1000 (Siemens) WWER 1000 (Russia)	Advanced Passively Safe LWRs: AP600 (Westinghouse); SBWR (General Electric); SIR (CE), B600 (B & W); AC-600 (CNNC) MS-600 (Mitsubushi) WWER-640 (Russia)	PIUS (ABB) SPWR (JAERI)
Heavy Water Reactor (HWR)	Candu 3 (AECL)		Advanced CANDU (AECL)
Gas-cooled Reactos			MHTGR (GA) MHTGR (ABB/Siemens)
Breeders	EFR (EFRA)		PRISM (General Electric)

ABWR = Advanced Boiling Water Reactor
APWR = Advanced Pressurized Water Reactor
AP600 = Advanced Passive 600
EFR = European Fast Reactor
EPR = European Pressurized Water Reactor
MHTGR = Modular High Temperature Gas-cooled Reactor
SBWR = Simplified Boiling Water Reactor
SIR = Safe Integral Reactor
PIUS = Process Inherent Ultimately Safe Reactor
PRISM = Power Reactor Inherently Safe Module

AECL = Atomic Energy of Canada Ltd.
B & W = Babcock & Wilcox
CE = Combustion Engineering (owned by ABB)
CNNC = China National Nuclear Corporation
EFRA = European Fast Reactor Asociates
JAERI = Japan Atomic Energy Research Institute
GA = General Atomics
Hi = Hitachi
NPI = Nuclear Power International (Siemens and Framatome)
To = Toshiba

Therefore, it recommended no federal funding for the further (commercial) development of these designs. The Committee instead recommended funding the development of a Liquid Metal Fast Breeder Reactor (LMFBR) as long-term option. The report thus questioned the sense of developing inherently safe reactors in the short and in the long run. Nevertheless, in actual reactor development the inherently safe nuclear reactor still seems to be accepted as long-term option. This is both true with respect to the activities of the nuclear reactor vendors and the activities and priorities of governmental agencies and research groups.
So, inherent safety has been fitted into a new strived-for innovation pattern in which innovations take place in successive generations. Meanwhile, inherent safety as a new guiding principle, implying a radically new way of designing nuclear reactors has almost been forgotten.[181] This is underlined by the fact that in IAEA documents like the recently published *Development of Safety Principles for the Design of Future Nuclear Power Plants* (TECDOC 801) and the recently issued international *Convention on Nuclear Safety* defense in depth is named as the strategy to prevent severe nuclear accidents; inherent safety is not mentioned.[182]

7.2.5 Transformation of the Technological Regime of Nuclear Reactors

For the proponents of inherent safety, the term referred to several things. It implied a new legitimating principle; inherently safe nuclear reactors should convince the public of the safety of nuclear power. Inherent safety also implied a new design approach. Instead of adding safety features to a reactor design chosen for other reasons (defense in depth), the choice of the reactor itself should follow from a safety philosophy. Third, inherent safety stood for new design criteria with respect to safety like passive safety, transparency, simplicity and ruggedness. Finally, inherent safety stood for particular reactor configurations and types. For its proponents, then, inherent safety amounted to a new guiding principle. This principle was to be used as legitimating principle vis-à-vis outsiders like politicians and the public. By being translated into more concrete design criteria and reactor features, inherent safety was to guide reactor design and development.
This definition of inherent safety was unacceptable to most regime insiders. They feared that inherent safety used in the proposed sense would further delegitimize existing nuclear reactors and their own past actions. Most regime insiders were also skeptical about the claim that inherent safety would solve problems like growing costs, lengthy licensing, doubts about safety and public protests.

Like the LWR and the breeder, the inherently safe nuclear reactor was presented as a technological fix to a number of societal and institutional problems. As such, it reflected the technological enthusiasm that had been so predominant in the nuclear reactor regime in the sixties and early seventies. The technological promise of the inherently safe reactor was, however, less easily accepted than those of the LWR and the breeder. One reason was that the idea of inherent safety implied an implicit critique and delegitimation of existing reactors. Another reason was the experience with LWRs, which had made the actors involved more skeptical toward technological promises. Therefore, utilities and reactor vendors aim at an innovation pattern that - although it is R&D-dependent and retains the idea of different generations - is based on smaller steps between the different generations than before. Eventually, inherent safety was not rejected by regime insiders but was redefined as a technical feature of next-generation designs. In this way, inherent safety was made more acceptable to regime insiders. Moreover, it could be fitted into the new strived-for innovation pattern. Because of this redefinition, other connotations of 'inherent safety' were increasingly 'forgotten.'

In its redefined form, inherent safety was enabled by the existing R&D-dependent innovation pattern. Research institutes and reactor vendors incorporated inherent safety as technical feature in next-generation reactor designs. Alleged inherently safe reactors were defined as so-called third generation designs.

Reactor types like the MHTGR and the PIUS may be commercially produced in twenty years. It is, however, doubtful whether they will be accepted by nuclear opponents, or the rest of the public. For nuclear opponents, and for a part of the public as well, safety is only one of the reasons for opposing nuclear power. Problems like nuclear waste disposal, proliferation of nuclear arms and the fear of a police state are not solved by inherently safe nuclear reactors. Therefore, most environmental and anti-nuclear groups in the United States and Europe have been very skeptical about the inherent safety movement.[183] For them, inherent safety is at best a solution to one of the problems of nuclear energy, making this option a little less unacceptable, but not necessarily acceptable. Moreover, most environmental and anti-nuclear groups consider it more cost-effective to invest in sustainable energy sources like solar and wind energy. Greenpeace, WISE (Worldwide Information Service for Energy) and the Worldwatch Institute have dismissed the striving for inherent safety in a 1992 Report as follows:

> *As the magnitude of the problems facing nuclear power has become clear, nuclear proponents have begun to urge the pursuit of a new generation of so-called "passively safe" reactors. This concept, which has quickly gained adherents in the past few years, is rooted in the notion that the industry's problems are caused by the high costs, unreliability, and licensing difficulties of today's technologies. At least eight new reactor designs have been proposed, and while they vary considerably and offer a number of intriguing features, they share one characteristic: they are raw, untested concepts that raise a host of safety problems that could take decades to resolve. Indeed, 30 years into the era of light water reactors, engineers are still finding new and unexpected problems with them. A recent study of three of the proposed new reactor designs by the Union of Concerned Scientists found that all are vulnerable to catastrophic accidents that can only be avoided by the successful operation of "active" safety systems. And just as at Three Miles Island and Chernobyl, these reactor designs appear not to be immune to human mistakes and will produce radioactive waste.*[184]

So, inherently safe reactors are clearly not safe from attacks by nuclear opponents. Most of the anti-nuclear movement has interpreted the striving for inherent safety as a technological fix to several problems that are, in their eyes, essentially social and institutional. Moreover, they believe that inherently safe nuclear reactors will eventually be plagued by 'unexpected' secondary effects, just like earlier nuclear reactors were.

7.3 Discussion and Conclusion

The processes of transformation studied in this chapter set off in somewhat different ways. In the case of aero-engines, the process of transformation started when outsiders made manifest the aggression of the existing technological regime. A harmful secondary effect, noise, was fed back to the existing regime via the route of regulation. In this way, noise was translated into an important design criterion in the technological regime of aero-engines. This did, however, not completely solve the aircraft noise problem. The way discussions about noise regulation have become organized in the world of commercial flight means that noise rules are adapted to what is considered, by conservative estimates, technically feasible and economically acceptable. Moreover, noise abatement has until now taken the form of a technological fix. Noise was mainly reduced by technical measures with respect to aircraft and aero-engine design. In the future, it may become increasingly necessary to bend back the growth in air transport.
The process of transformation studied with respect to the regime of nuclear reactors set off as a demand. A group of maverick scientists, who became involved via a demand, proposed inherent safety as a new guiding principle. This demand was both the result of internal problems within the technological regimes of nuclear reactors and nuclear protests in reaction to the aggression of the technological regime toward the environment. By its proponents, inherent safety was meant as a new guiding principle that should convince the public of the safety of nuclear reactors. Moreover, by being translated into more concrete design requirements, heuristics and reactor configurations, it was to guide reactor design and R&D. In the event, neither anti-nuclear groups nor the traditional proponents of nuclear energy accepted inherent safety as a new guiding principle. Within the regime of nuclear reactors, inherent safety was eventually redefined as a technical feature of third generation designs. Research, development and testing of such reactors are now underway.

Both processes of transformation were enabled by the R&D-dependent innovation pattern. Universities, government research institutes and R&D laboratories proactively undertook R&D anticipating on future societal and technical developments. We see at work a dynamics of expectations that is comparable to what we observed in Chapter 4, when discussing the supplier-dependent innovation pattern. In a supplier-dependent innovation pattern, suppliers proactively develop new technical configurations, while in an R&D-dependent innovation pattern, researchers do so.
The proactive undertaking of R&D is clearly visible in the aero-engine story. Scientific research and R&D already started before noise certification rules were

considered. In the event, this enabled the issuing of certification because it was clear that noise-abatement technology was available or could soon come available.
In the nuclear reactor story, we also observed some proactive development of technical alternatives. An example is the development of the PIUS reactor by ABB in Sweden in anticipation of a possible ban of nuclear energy in that country (and other countries), and the diffuse expectation that inherently safe nuclear reactors would be more easily accepted by the public and politicians.
Apart from the fact that researchers proactively undertook R&D, the technological regimes of aero-engines and nuclear reactors had another characteristic that enabled the studied processes of transformation: the high rate of technological change and the fact that innovation took place in successive generations. This meant that noise abatement respectively inherent safety features could be incorporated in next-generation designs.
The strived-for-changes were, however, only incorporated in the existing innovation dynamics after they were redefined so that they could more easily be fitted into the existing innovation dynamics. This redefinition was achieved through processes of technical agenda building in such fora as the ICAO (aero-engines) and the IAEA (nuclear reactors). The access to these fora was in both cases restricted to actors with an interest in the viability of air transport respectively nuclear power. These actors did not resist changes in the existing regime per se, but they tried to redefine these changes so that the resulting transformation would only be moderate. In the case of aero-engines, this meant that noise certification was adapted to what was considered technically and economically feasible by conservative estimates in the world of commercial flight. In the case of nuclear reactors, inherent safety was redefined as a technical feature that could be fitted into the strived-for-innovation pattern of the regime.

In both cases, the R&D-dependent innovation pattern resulted in a technological fix. Safety problems of nuclear reactors and noise problems of aero-engines were not solved by institutional options but by new technology. The occurrence of a technological fix is related to the fact that in regimes with an R&D-dependent innovation pattern innovations start with technological promises to become aligned to functions only later. This focus on technological promises gives researchers the opportunity to lose themselves in technological enthusiasm. If they or other actors later do not succeed in aligning the new technical options with functions, failures like the Concorde may follow.
The occurrence of such failures is not necessarily due to the fact that researchers are too enthusiastic about technical options. It may also be that 'gaps' exist in the overall division of labor, so that too few efforts are undertaken to make technical options economically and socially viable. As a result, even technical options implemented on some scale may lose their viability, as happened with nuclear reactors.
The important point is that a bias toward technological newness and technological enthusiasm is, to some extent, institutionalized in an R&D-dependent innovation pattern. In this innovation pattern, it is the role of researchers to think out new promising technological options, even if it is not quite clear to what kind of functions such options might be aligned. While this bias enables technological change and the

transformation of a technological regime, it meanwhile introduces the risk that new technological options are developed that can never successfully be aligned to functions, or that produce as much or even more harmful secondary effects as their predecessors. While a technological fix enables the transformation of a technological regime, it may well constrain the better fulfillment of functions or the taking away of harmful secondary effects.

Notes to Chapter 7

1 This case study draws heavily on M.J.T. Smith, *Aircraft Noise* (Cambridge Aerospace Series) (Cambridge etc.: Cambridge University Press, 1989).

2 Smith, *Op. cit.*, xi.

3 Smith, *Op. cit.*, 21-22 and 53.

4 The growing noise problem had also other reasons like the expansion of living areas in the direction of airports.

5 Already in 1959, an American FAA administrator felt forced to get a secret phone number, because he was kept awake by complaining citizens (F.A. Spencer, *Transport Jet Aircraft Noise Abatement in Foreign Countries: Growth, Structure, Impact* (1980), Report for NASA Ames Research Center, Vol. 1, 1).

6 J.J. Jenkins, 'The Airport Noise and Capacity Act of 1990; Has Congress Finally Solved the Aircraft Noise Problem?,' *Journal of Air Law and Commerce*, 59(1994), 1023-1055, especially page 1025-1027. This decision has been upheld in other cases. Airlines using the airport cannot be held liable.

7 Smith, *Op. cit.*, xi and 20-21.

8 Spencer, *Op. cit.*, Vol. 1, 1; Smith, *Op. cit.*, 22.

9 Spencer, *Op. cit.*, Vol. 2, 167-183.

10 *Cf. Ibid.*, Vol. 1, 12 and Vol. 2, 169-171 and 182-183.

11 *Ibid.*.

12 Jenkins, *Op. cit.*.

13 The description of the measures taken by the FAA and the ICAO is based on Smith, *Op. cit.*, 20-40 and Spencer, *Op. cit.*, Vol. 1, 1-15.

14 Cited in Smith, *Op. cit.*, 22.

15 The ICAO rules apply to the countries that are member of the ICAO. Annex 16 has only legal force if it is legislated by national governments. It took until 1979 before the European Economic Commission (EEC) translated Annex 16 in an EEC Directive (Spencer, *Op. cit.*, Vol. 1, 10-11). FAR Part 36 and Annex 16 roughly employ the same framework for noise certification. Both set limits for noise at three reference points: at take-off, approach and at the sideline. Both formulated 108 EPNdB as never to exceed noise level; although also more stringent standards were formulated, depending on gross weight of the aircraft and the number of engines (Smith, *Op. cit.*, 26).

16 Smith, *Op. cit.*, 26-27. In the case of FAR, noise rules became mandatory retroactive as of January 1969.

17 Recently, and due to the success of efforts to silence the aero-engine, also other parts of the aircraft, like the airframe, have become relatively more important sources of aircraft noise.

18 For more details, see Appendix 3.

19 R. Miller & D. Sawers, *The Technical Development of Modern Aviation* (London: Routledge & Kegan Paul, 1968); Nelson & Winter (1982); D. Todd & J. Simpson, *The World Aircraft Industry* (Dover (Ma.): Croom Helm, 1986). Given are the dates when the new technologies are *applied* at a serious scale to aircraft and aero-engine design. This is evidently not the same date as the invention. The first three phases are based on Miller & Sawers (*Op. cit.*, 257-263). They give the following dates 1908-1912, 1930-1933, 1942-1947. I have defined the phases somewhat broader and changed the dates of the final period because the dates given by Miller

& Sawers also relate to the application in military design. The turbojet was first used for military purposes and only later applied to civil aviation. For the (third and) fourth phase see the literature cited in note 20.

20 The description below of the turboprop and the turbofan is based on Smith, *Op. cit.*; Anonymus, *The Jet Engine* (Derby (England): Rolls-Royce, 1986); C.H. Gibbs-Smith, *The Aeroplane; An Historical Survey of its Origins and Development* (London: Her majesty's stationery office, 1960); J.L Kerrebrock, *Aircraft Engines and Gas Turbines* (Cambridge (Ma.): MIT, 1977); P.J. McMahon, *Jet Engines and Rocket Propulsion* (London: The English Universities Press, 1964), 43-46 and G.J.J. Ruijgrok, *Elements of Aviation Acoustics* (Delft: Delft University Press, 1993).

21 Figure 1 is based on figure 12.1-1, 12.1-3, 12.1-4 and 12.1-5 from Ruijgrok, *Op. cit.*, 255-259 and figure 3.12 from Smith, *Op. cit.*, 59.

22 Miller & Sawers, *Op. cit.*, 25-27.

23 It is used today at many small commuter aircrafts (Ruijgrok, *Op. cit.*, 259).

24 McMahon, *Op. cit.*, 45-46.

25 *Ibid.*.

26 Smith, *Op. cit.*.

27 F.B. Greatrex & R. Bridge, 'The Evolution of the Engine Noise Problem,' *Aircraft Engineering*, February 1967, 8; Smith, *Op. cit.*, 62.

28 This subsection is based on the literature cited in note 20 and on Greatrex & Bridge, *Op. cit.*; NASA Lewis Research Center, *Aircraft Noise Reduction Technology* (Sprongfield: National Technical Information Service (NTIS), 1973), NASA TM X-68241; W.L. Steward, D.L. Nored, J.S. Grobman, *et al.*, 'Preparing Aircraft Propulsion for a New Era in Energy and Environment,' *Astronautics & Aeronautics*, January 1980, 18-30 and 37; H. Wittenberg, *Het ontwerpen van vliegtuigen* (Delft: Waltman, 1961), Rede, uitgesproken bij de aanvaarding van het ambt van gewoon hoogleraar in de vliegtuigbouwkunde aan de Technische Hogeschool te Delft op woensdag 15 november 1961; J.H.D. Blom, *Verkeersvliegtuigen; twintig jaar evolutie* (Delft: Delftse Universitaire Pers, 1988), Rede, uitgesproken bij het afscheid als buitengewoon hoogleraar in het ontwerpen van vliegtuigen bij de Faculteit der Luchtvaart- en Ruimtevaarttechniek van de Technische Universiteit Delft op donderdag 11 februari 1988, 21-23; 'Aeroacoustics' 1978-1992 in *Astronautics & Aeronautics* (December 1978, 20-22; December 1979, 26-27; December 1980, 22-23; December 1981, 28-29; December 1982, 22-26 and December 1983, 26-28) and *Aerospace America* (December 1984, 66; December 1985, 47; December 1986, 48; December 1987, 75; December 1988, 36; December 1990, 35; December 1991, 73 and December 1992, 16); *Astronautics & Aeronautics*, July/August 1981, 45-46; and interview Schulten, 30 June 1994, interview Cornelisse, Sarin and Joustra, 20 June 1994 and interview Ruijgrok & Van Paassen, 6 July 1994.

29 In the twenties, for example, some of the mechanisms that created propeller noise were studied. According to Smith, *Op. cit.*, a lot of the early interest in propeller noise was either academic or superficial.

30 M.J. Lighthill, 'On Sound Generated Aerodynamically; I: General Theory,' *Proceedings of the Royal Society*, Series A, 211(1952), 564-587.

31 The status of Lighthill as founding father of aeroacoustics is also clearly observable in what was probably the first textbook specifically devoted to this subject, the book *Aeroacoustics* (New York etc.: Mc Graw-Hill, 1979), written by Marvin E. Goldstein, a research engineer working at NASA Lewis Research Center. There is no journal specially devoted to aeroacoustics, but aeroacoustic conferences are held on a regular basis and, for example, the journal *Astronautics & Aeronautics* yearly pays attention to developments in aeroacoustics (Interview Schulten, 30 June 1994).

32 In the course of time, two kinds of problems have become especially apparent with respect to test results obtained at static rigs. A first problem was the contamination of tests results with secondary noise sources or resulting from poor aerodynamics. By and large, this problem could be overcome by using anechoic test facilities. A second problem was anomalies arising from differences between static and in-flight tests at various flight speeds. This problem became especially apparent in the seventies. By then, it turned out that a particular fan noise reduction

technology, which seemed not to function in static tests, obtained good results in flight tests. The subject led to some controversy. Eventually it was concluded that inlet air at static facilities was of a different aerodynamic 'quality' than inlet air in flight. Now, devices were developed to treat inlet air at static facilities as to make the results obtained comparable to in-flight conditions. Most manufacturers now use such devices as to be able to test fan, compressor and turbine noise at static facilities.

33 Like static rigs, wind tunnels had to be made aerodynamically 'clean' to obtain reliable data. When designers of wind tunnels succeeded in making those tunnels, or sections of them, aerodynamically 'clean,' wind tunnels increasingly became a standard facility to examine speed effects.
Wind tunnels can now be found at some of the larger manufacturers, for example Boeing's transonic wind tunnel, at government research institutes, for example at NASA-Lewis and NASA-Ames, and at governmental-industrial establishments, like the Dutch-German wind tunnel. If scale model tests are carried out at wind tunnels, scaling laws are required to translate the results obtained to the in-flight case. Flight tests may be required to correct the scaling laws or to discover contaminating noise sources.

34 An important computer code developed by NASA Langley for predicting aircraft noise is ANOPP. This code may be used for a number of purposes like providing estimates of flyover noise of new aircrafts, studying the tradeoffs between different design criteria or requirements like noise and defining areas for further noise research.

35 Smith, *Op. cit.*, 157.

36 *Ibid.*. One especially important program for the development of noise reduction technology was the NASA Quiet Engine Program (NASA Lewis Research Center, *Op. cit.*).

37 Smith, *Op. cit.*, 120-134.

38 Also so-called ejectors were proposed ro reduce noise, while augmenting thrust. Although ejector test programs have been carried out, they have not been put in practice. Interest in ejectors, however, has revived several times. For example in relation to the aero-engines of SST aircrafts (*ibid.*, 128-131).

39 Greatrex & Bridge, *Op. cit.*, 8; Smith, *Op. cit.*, 62.

40 Tyler, J.M. & T.G. Sofrin, 'Axial Compressor Noise Studies,' *SAE Transactions*, 70(1962), 309-332.

41 This figure is based on the figures 4.21 and 4.24 from Smith, *Op. cit.*, respectively on page 138 and 142. For a description of the various measures see Greatrex & Bridge, *Op. cit.*, NASA Lewis Research Center, *Op. cit.*, Ruijgrok, *Op. cit.*, Smith, *Op. cit.*, 57-97 and 134-152.

42 Smith, *Op. cit.*, 138.

43 Smith, *Op. cit.*, 27.

44 *Ibid.*, 26-27.

45 These were types like the Boeing 727, the Boeing 737 and the DC-9, which were powered by like JT3D and Pratt & Whitney's JT8D and Rolls Royce's Spey.

46 FAR Part 36, Amendment 2; Annex 16, Amendment 1.

47 FAR Part 91, Amendment 136.

48 The same kind of strategies, in principle, stood open for the manufacturers of aero-engines. They could stop the production of older aero-engines not meeting the noise rules or adopt them somewhat by hushkits in order to let meet the aircrafts the new noise rules.

49 *Flight International*, 148(1995)4495, 23-26.

50 *Flight International*, 150(1996)4537, 50-53 and 148(1995)4495, 23-26; *Interavia Aerospace Review*, 3(1990), 207-211.

51 The noise of Pratt & Whitney's JT8D, for example, 'the most used aero-engine ever' (Smith, *Op. cit.*, 18) which powered over 3,800 airplanes, was lowered with acoustic liners by some dB as to fall just within the new limits. Later, a refanned version of the JT8D was developed, which had a higher bypass ratio and hence a lower exhaust speed (*Ibid.*, 133).

52 Hushkit manufacturers claim that most of their hushkits do not lower the propulsive efficiency. *Cf. Flight International*, 148(1995)4495, 23-26.

53 Producers of hushkits include Nordam, Quiet Nacelle (QNC) and Burbank Nacelle.

54 This section is mainly based on *Aerospace America*, October 1993, 8-11; *Airline Business*, 12(1996)3, 26-29; *Astronautics & Aeronautics*: February 1976, 5-7; April 1977, 52-55; October 1977, 42-55; June 1979, 65-66 and 70; *Aviation Week & Space Technology*, 139(1993)13, 32-33; *Flight International*, 148(1995)4495, 23-26; 150(1996)4537, 50-53; *ICAO Journal*, 50(1995)2, 18-19 and 29; 51(1996)2, 5-8 and 15-16; *De Ingenieur*, 90(1978)49, 949-952; *Interavia Aerospace Review*, 3(1990), 207-211; May 1991, 15-17; Jenkins, *Op. cit.*; Ruijgrok, *Op. cit.*; Smith, *Op. cit.*; Spencer, *Op. cit.*.

55 The term ‘world’ is used here in accordance with the concept of ‘social world’ developed by Anselm Strauss (see, for example Strauss, 1978). Social world may contain one or more technological regimes (*cf.* Van de Poel, 1994 and Van de Poel & Disco, 1996).

56 To give an impression of the number of groups that may be involved: at one airport hearing in Britain more than a hundred groups wanted to speak out (Spencer, *Op. cit.*, Vol. 1, 15).

57 Spencer, *Op. cit.*, Vol. 1, 12.

58 Anti-noise and environmental groups are hardly represented at the international level. Environmental government agencies and ministries are represented via their national governments, which also defend the interests of national airlines and national economic interests.

59 *Airline Business*, 12(1996)3, 26-29.

60 *Ibid.*.

61 *Astronautics & Aeronautics*, February 1976, 7; *ICAO Journal*, 51(1996)2, 5. The same type of criteria are used by the FAA in proposing new noise certification rules in the USA.

62 FAR Part 36, Amendment 7; Annex 16, Amendment 3.

63 Ruijgrok, *Op. cit.*, 216; Spencer, *Op. cit.*, Vol 1, 29. Stage 3 (FAR) became effective as of 1 November 1977 and applied to subsonic aircrafts certified after 5 November 1975 (Spencer, *Op. cit.*, Vol 1, 2).

64 Smith, *Op. cit.*, 34.

65 *Aerospace America*, October 1993, 9.

66 *Interavia Aerospace Review*, May 1991, 17.

67 *Ibid.*, 15-17.

68 *Ibid.*, 17.

69 In 1988, the European Aviation Conference (ECAC; the European counterpart of the ICAO) adopted a non-addition rule, which implied that member countries were no longer allowed to add Chapter 2 aircrafts to their airline registers as of October 1990. A similar measure of the European Union (EU) became effective in November 1990 (*Interavia Aerospace Review*, 3(1990), 208).

70 *ICAO Journal*, 51(1996)2, 5; *Interavia Aerospace Review*, May 1991, 15-16.

71 Jenkins, *Op. cit.*, 1036-1053.

72 Airlines may choose for two different schemes for phasing out their Stage 2 aircrafts; a so-called phase-out and a so-called phase-in option. The phase-out implies that airlines have to phase out at least 25% of their Stage 2 aircrafts in 1994, 50% in 1996, 75% in 1998 and eventually 100% in 2000. The phase-in option implies that airlines have to have a fleet consisting of at least 55% Stage 3 aircrafts by 1994, 65% in 1996, 75 % in 1998 and 100% by 2000 (Jenkins, *Op. cit.*, 1046). For 1996 these goals will be reached by all airlines (‘Aircraft noise levels continue to decline, secretary Peña announces,’ News release US Department of Transportation, 2 October 1996).

73 *Aviation Week & Space Technology*, 6 June 1994.

74 Interview Cornelisse, Sarin and Joustra, 20 June 1994.

75 *Airline Business*, 12(1996)3, 26-29; *ICAO Journal*, 51(1996)2, 5-8.

76 *ICAO Journal*, 51(1996)2, 6.

77 *Airline Business*, 12(1996)3, 26-29.

78 This box is mainly based on Smith, *Op. cit.*, 153-175. See also P.W. Brooks, 'Aircraft and Their Operation', in T.I. Williams (ed.), *A History of Technology (Volume VII)* (Oxford: Oxford University Press, 1978), 789-836; K. Hayward, *The British Aircraft Industry* (Manchester & New York: Manchester University Press, 1989), 100-114; H. Wittenberg, *De ontwikkeling van vliegtuigen met snelheden groter dan de geluidssnelheid*, Delft: Waltman, Rede, uitgesproken bij de aanvaarding van het ambt van lector in de vliegtuigbouwkunde aan de Technische Hogeschool te Delft op 2 juni 1955, 11; Wittenberg, *Op. cit. 1961*, 10 ff.; Miller & Sawers, *Op. cit.*, 281-286; *De Ingenieur*, 85(1973)17, 343-348 and 90(1978)49, 949-952; *Astronautics & Aeronautics*, January 1975, 24-35 and May 1975, 38-45; *Aerospace America*, September 1991, 20; *ICAO Journal*, 51(1996)2, 15-16.

79 *Airline Business*, 12(1996)3, 26-29; *ICAO Journal*, 51(1996)2, 6.

80 For SST see literature note 78. For VLA see *Flight International*, 145(1994)4424, 43 and *Air Transport World*, 30(1993)5, 74-78.

81 *Ibid.*.

82 Jenkins, *Op. cit.*, 1037.

83 *Ibid.*.

84 This figure is reproduced from Smith, *Op. cit.*, 249.

85 Lilienthal, *Atomic Energy; A new Start* (New York etc.: Harper & Row, 1980), 109.

86 In the first decade after the Second World War, the efforts in the USA to develop nuclear reactors for civil applications were restricted by military considerations. The USA wanted to keep its monopoly on the atomic bomb. Until 1954, private ownership of nuclear plants was forbidden and the American government had a strict and exclusive authority over the development and use of (civil) nuclear reactors. The Atomic Energy Commission (AEC) undertook a number of projects to develop civil nuclear reactors. After 1953, the USA shared its nuclear technology with some other countries in the 'Atoms for Peace' program. For more details, see Appendix 3. For early reactor development in the USA, see Lord Hinton of Bankside, 'Atomic Energy,' in T.I. Williams (ed.), *A History of Technology (Volume VI)* (Oxford: Oxford University Press, 1978), 223-267; I.C. Bupp & J.-C. Derian, *Light Water; How the Nuclear Dream Dissolved* (New York: Basic Books, 1978); J.M. Jasper, *Nuclear Politics; Energy and the State in the United States, Sweden, and France* (Princeton: Princeton University Press, 1990); G.T. Mazuzan & J.S. Walker, *Controlling the Atom; The Beginnings of Nuclear Regulation 1946-1962* (Berkeley etc.: University of California Press, 1984), 1-31.

87 See Appendix 3, for the developments in other countries.

88 The LWR submarine project was so successful that in 1952 the LWR design was chosen by the AEC for a major power reactor development project.

89 Until then, nuclear energy was not seen as competitive on purely economic grounds by American utilities (Bupp & Derian, *Op. cit.*; Jasper, *Op. cit.*).

90 The description of the development of the nuclear bandwagon market in the USA is merely based on Bupp & Derian, *Op. cit.* and Jasper, *Op. cit.*.

91 Jasper, *Op. cit.*, 45.

92 Bupp & Derian, *Op. cit.*, 74-76 give four possible reasons why utilities so 'easily' accepted these turn key contracts: 1) subsidies of the AEC; 2) the fear to be squeezed out of business by publicly managed companies; (The example that stood out was the Tennessee Valley Authority which had become a regionally dominant electricity producer by exploiting coal.) 3) the seemingly predictability of the environment and the feeling that the power sector was ready for a new technology; 4) the belief in and the good experience with 'technological progress' of many professionals who were active in the utility business. Some of these reasons may also explain why it took some time before utilities began to assess critically the 'real' (in contrast to the 'estimated') costs of nuclear power.

93 Bupp & Derian, *Op. cit.*; F.G. Dawson, *Nuclear Power; Development and Management of a Technology* (Seattle and London: University of Washington Press, 1976, 140-143.

94 Bupp & Derian, *Op. cit*..

95 *Ibid.*, 73.

96 Jasper, *Op. cit.*, 49.

97 Bupp & Derian, *Op. cit.*; D. Burn, *Nuclear Power and the Energy Crisis; Politics and the Atomic Industry* (London and Basingstoke: Macmillan Press, 1978).

98 The description below of the licensing of nuclear reactors in the period until the sixties is mainly based on D. Okrent, *Nuclear Reactor Safety; On the History of the Regulatory Process* (Wisconsin: The University of Wisconsin Press, 1981). See also Mazuzan & Walker, *Op. cit.*.

99 *Cf.* Okrent, *Op. cit.*.

100 In 1950, the RSC had adopted a restrictive rule of thumb for reactor siting with related the required population exclusion distance around the reactor to the reactor power.

101 10 CFR 100 contained also siting criteria. Sometimes, siting criteria for individual reactors were loosened if extra safety features were added, exchanging 'distance' for added safety measures.

102 Burn, *Op. cit.*, 45.

103 *Cf.* Okrent, *Op. cit.*.

104 The box on defense in depth is mainly based on S. Glasstone & A. Sesonske, *Nuclear Reactor Engineering* (Third Edition) (New York etc.: Van Nostrand Reinhold, 1981), 683-687; P. Mostert, 'Reactorveiligheid,' in C.D. Andriesse & A. Heertje (eds.), *Kernenergie in beweging; Handboek bij vraagstukken over kernenergie* (Amsterdam: Keesing Boeken, 1982), 61-73; The Nuclear Energy Policy Group, 'Reactor Safety,' in The Nuclear Energy Policy Study Group (ed.), *Nuclear Power Issues and Choices* (Cambridge (Ma.): Ballinger, 1977), 213-24; P. Schmitz & R. Griffen, 'Power Reactor Containment,' *Nucleonics*, October 1965, 50-55.

105 Okrent, *Op. cit.*. On the ECCS controversy see also Bupp & Derian, *Op. cit.*, 132-136; F.C. Finlayson, 'A View from the Outside,' *Bulletin of the Atomic Sciences*, 1975, 20-25; R. Gillette, 'Nuclear Reactor Safety; A New Dilemma for the AEC,' *Science*, 9 July 1971, 126-130; R. Gillette, 'Nuclear Reactor Safety; A Skeleton at the Feast?,' *Science*, 28 May 1971, 918-919; Jasper, *Op. cit.*, 54-57; J.E. Speelman, 'De ontwikkeling van veiligheidsanalyses voor kerncentrales,' *Energiespectrum* 11(1987)4, 102-107.

106 *Cf.* Okrent, *Op. cit.*.

107 These tests were carried out at the Loss Of Flow Test (LOFT) facility in Idaho. This facility had been built in the early sixties to study the effects of a Loss-of-coolant accident (LOCA). At the end of the sixties, the objectives of the LOFT program were reformulated as a result of a report of the Ergen Committee. This committee was formed in 1966 by the AEC as to give advice on the problems of extrapolating 100 megawatt (electricity output) reactor designs to 1000 megawatt designs which were then proposed by the nuclear reactor vendors. While the ACRS was dissatisfied with the way the Ergen Report treated the issue of core melt, the report nevertheless led to growing attention for the ECCS. This resulted in a redesign of the LOFT facility as to make possible tests with the ECCS. The 1971 tests were 'only' preliminary test to control the calculation and simulation programs that were formulated for the test. 'Real' experiments at the LOFT facility did not start until 1984 (Speelman, *Op. cit.*, 103).

108 This subsection is mainly based on Bupp & Derian, *Op. cit.*; Burn, *Op. cit.* and Jasper, *Op. cit.*.

109 Burn, *Op. cit.*, 31.

110 Bupp & Derian, *Op. cit.*, 72-73.

111 Burn, *Op. cit.*, 44.

112 According to Burn (*Op. cit.*, 43) almost two thirds of the cost increases arising from changes in design and specification were related to 'safety and environment.'

113 Bupp & Derian, *Op. cit.*, 154-155. For both explanations there is some evidence (see also Burn, *Op. cit.*, 30-51; Jasper, *Op. cit.*, 195-197). Most of the issues named by the utilities, however, seem in the final analysis related to the lack of operating experience, which hindered the expected 'learning process.' (Bupp & Derian, *Op. cit.*, 155). Or better: learning did not take place, but 'much of it was learning to do things more expensively' (Burn, *Op. cit.*, 43).

114 Jasper, *Op. cit.*.

115 *Cf.* Burn, *Op. cit.*, 45-46, 51 and 82-84.

116 This ‘splitting up’ was to an important degree the result of the growing (public) criticism of the AEC after the ECCS controversy. It was hoped that by splitting the AEC public confidence would be restored. In turn, this might - so was hoped - streamline the licensing process.

117 In the USA, PUCs and the Federal Energy Regulatory Commission control electricity rates and in this way they determine investment returns. In some cases they have decided that ‘unnecessary’ costs might not lead to higher electricity rates. These unnecessary costs were often determined looking back, and concerned in a lot of cases costs overruns on nuclear constructions due to poor management or expenses for what appeared to be superfluous nuclear capacity (R.K. Lester, ‘Rethinking Nuclear Power,’ *Scientific American*, 254(1986)3, 23-31). Ironically, the oil crisis may have been a cause of the financing difficulties of utilities in two respects. First, it created the apparatus and the will to assess and compare different energy options more throughout. Second, it may have been a source of doubts about the earlier estimates of growing energy demand (*cf.* Jasper, *Op. cit.*).

118 Jasper, *Op. cit.*, 213.

119 *Cf.* Bupp & Derian, *Op. cit.*, 70-89.

120 Bupp & Derian, *Op. cit.*.

121 Some of the factors, in addition to those explained above, that resulted in this lock-in are described in Appendix 3.

122 This argument is put forward by many proponents of inherently safe nuclear reactors. See Section 7.2.3.

123 Bupp & Derian, *Op. cit.*, 179-185.

124 This decision was only indirectly related to the commercial success of the LWR. In 1964, Shaw became Director of Reactor Development of the AEC. He wanted to start an aggressive government-controlled reactor development program. In his eyes, this program should be based on a ‘second generation’ of nuclear power plants which were less wasteful of uranium and thermodynamically more efficient than the LWR. Initially, the AEC decided to concentrate its efforts on the development of the High Temperature Gas-cooled Reactor (HTGR). The HTGR program was, however, hardly the kind of aggressive governmental-controlled program Shaw advocated. In 1965, Shaw succeeded in shifting emphasis from the HTGR program to breeder reactor development. Now the government indeed became responsible for the complete development of a new reactor generation. In the following years, Shaw was prepared to sacrifice other activities for the reactor development program, resulting in a relative neglect of LWR safety issues by the AEC (Bupp & Derian, *Op. cit*., 50-55).

125 Jasper, *Op. cit.*, 61-62.

126 Bupp & Derian, *Op. cit.*.

127 This section is mainly based on Jasper, *Op. cit.*, 108-114 and 178-184 and D. Nelkin & M. Pollak, *The Atom Besieged; Extraparliamentary Dissent in France and Germany* (Cambridge (Ma.): MIT Press, 1981). For protests in the Netherlands, see E. Abma, H.P.M. Jägers & G.J. van Kempen, ‘Kernenergie als maatschappelijke splijtstof, een analyse van een protestbeweging,’ in P. Ester & F.L. Leeuw (eds.), *Energie als maatschappelijk probleem* (Assen: Van Gorcum, 1981), 146-171.

128 The thermal efficiency of LWRs is about 18% lower than of conventional plants (Bupp & Derian, *Op. cit.*, 132).

129 Burn, *Op. cit.*, 47-48.

130 In Europe, nuclear protests started in the early seventies. Initially it were ‘spontaneous events,’ but between 1973 and 1975 most protest movements became national in scope. In some European countries, like the Netherlands, scientists played an important role in the early protests against nuclear energy; in others, like France, they came to play a role only later. In Europe, the student movement also to an important extent laid the ground for the anti-nuclear movement.

131 This ‘politicization’ of nuclear energy was not only due to nuclear protests but also to the 1973 oil crisis, which made energy policy in general, and nuclear energy policy in particular, an important political topic (Jasper, *Op. cit.*, 180-182).

132 Nelkin & Pollak, *Op. cit.*, 191. This especially seems to hold for Europe (*cf.* Bupp & Derian, *Op. cit.*, 147).

133 In the USA, nuclear opponents initially were politically not very successful. In 1976, referenda on nuclear power were organized in a number of states. In most states, nuclear proponents won these referenda by two against one (Bupp & Derian, *Op. cit.*, 144-147). In the eighties, nuclear opponents were politically more successful. By 1984, eleven states had laws restricting nuclear power in one way or the other. Most of these laws required full consideration of alternative means of power generation. These laws had, however, little direct effect since by then most utilities had already lost their trust in the nuclear option for economic reasons. In 1989, for the first time a referendum resulted in the closure of a nuclear plant in the USA (Jasper, *Op. cit.*, 206-208).

134 Bupp & Derian, *Op. cit.*, 157-160.

135 Jasper, *Op. cit.*, 209-210.

136 A.M. Weinberg, I. Spiewak, J.N. Barkenbus, *et al.*, *The Second Nuclear Era; A New Start for Nuclear Power* (New York: Praeger, 1985), 39.

137 Lilienthal, *Op. cit.*. Lilienthal was not the first one to pronounce the idea of inherent safety. Already in 1957 McCullough chairman of the American Reactor Safety Commission stated: 'There will be recognition by the atomic energy industry that true progress requires the development of increasing reliable and safe reactors. There will be developed reactors with inherent stability against nuclear transients. Cooling systems will be devised which can be considered truly reliable. On the other hand, means of containing reactors will be devised so that even if the machines are destroyed one is assured that employees and public are protected. New concepts will be developed. The newer reactors will be more economical than present designs.' (cited in B.Th.Eendebak, 'Actieve en passieve veiligheidssystemen bij kerncentrales,' *Energiespectrum*, January/February 1988, 6).

138 Lilienthal, *Op. cit.*, 99.

139 *Ibid.*.

140 A.M. Weinberg & I. Spiewak, 'Inherently Safe Reactors and a Second Nuclear Era,' *Science*, 29 June 1984, 1398-1402.

141 I. Spiewak & A.M. Weinberg, 'Inherently Safe Reactors,' *Annual Review of Energy*, (1985)10, 431.

142 Weinberg & Spiewak, *Op. cit.*, 1398.

143 Weinberg, Spiewak, Barkenbus, *et al.*, *Op. cit.,* v.

144 *Ibid.*, 11.

145 *Ibid.*.

146 *Ibid.,* 24 and 74.

147 Spiewak & Weinberg, *Op. cit.* 433.

148 Weinberg, Spiewak, Barkenbus *et al.*, *Op. cit.*, 11.

149 Spiewak & Weinberg, *Op. cit.*, 433-434.

150 G. Kelfkens, *Inherente veiligheid in perspectief* (Zoetermeer: Ministerie van Volksgezondheid, Ruimtelijke Ordening en Milieubeheer, 1994), Publikatiereeks Stoffen, Veiligheid, Straling nr. 1994/17, 68-69.

151 K. Lester, M.J. Driscoll, M.W. Golay, *et al.*, *National Strategies for Nuclear Power Reactor Development* (Cambridge (Ma.): Department of Nuclear Engineering Massachusetts Institute of Technology, 1985), Report No. MITNPI-PA-002.

152 *Cf.* Spiewak & Weinberg, *Op. cit.*, 432; J.N. Barkenbus, 'Prospects for Inherently Safe Reactors,' in L.D. Olthof (ed.), *Is kernenergie veilig?; Verslag van het congres van de Stichting Natuur en Milieu, gehouden op 23 april 1987 in de Koninklijke Jaarbeurs te Utrecht* (Utrecht: Stichting Natuur en Milieu, 1987), 19-34.

153 H.M.Agnew & Th.A. Johston, 'Chernobyl: The Future of Nuclear Power,' *Issues in Science and Technology*, Fall 1986, 36-39; T. Crane, 'Alternate Approaches to Nuclear Safety,' *Nuclear Safety*, 26(1985)4, 468-476; C.W. Forsberg & A.M. Weinberg, 'Advanced Reactors, Passive Safety, and Acceptance of Nuclear Energy,' *Annual Review of Energy*, (1990)15, 133-152;

A.A. Harms, B.W. Augenstein & N.S. Rabotnov, ‘Nuclear Energy: In Search of a Paradigm Shift,’ *Annals of Nuclear Energy*, 22(1995)5, 291-196; E. Lantz, ‘Letter to the Editor: Inherently Safe Nuclear Power Plants,’ *Nuclear Safety*, 21(1980)1, 25; Lester, *Op. cit.;* L.M. Lidsky, ‘The Reactor of the Future?,’ *Technology Review*, February/March 1984, 52-56; Spiewak & Weinberg, *Op. cit*.; Weinberg & Spiewak, *Op. cit.*.

154 Not all arguments outlined appear in all articles. Most of these arguments can also be found in *The Second Nuclear Era*. For these arguments see also Barkenbus, *Op. cit.*.

155 Transparent safety is sometimes used as equivalent to inherent safety. Transparent safety may, however, eventually also be reached by, for example, improved containment structures. See also the discussion about the question whether transparent safety will raise the acceptance of nuclear reactors in R. Krieg, ‘Can the Acceptance of Nuclear Reactors Be Raised by a Simpler, More Transparent Safety Concept Employing Improved Containments?,’ *Nuclear Engineering and Design*, (1993)140, 39-48.

156 This multiplicity of the term is also visible in the use of acronyms like PRIME reactors, which stand for Passive, Resilient, Inherent, Malevolent resistant, Extended safety (*Cf*. Forsberg & Weinberg, *Op. cit.*, 137).

157 Barkenbus, *Op. cit.* 24. This description below on the reaction to the striving for inherent safety by other actors in the regime of nuclear reactors is mainly based on Barkenbus, *Op. cit.* and Forsberg & Weinberg, *Op. cit.*.

158 *Cf.* Lester, Driscoll, Golay *et al.*, *Op. cit.*, 8.

159 Quoted in Spiewak & Weinberg, *Op. cit.*, 460.

160 *Cf.* T.J. Connolly, ‘Reflections on the Second Nuclear Coming,’ *Nuclear News*, April 1986, 45-50.

161 Lester, *Op. cit.*, 30.

162 Committee on Future Nuclear Power Development, Energy Engineering Board, Commission on Engineering and Technical Systems, National Research Council, *Nuclear Power; Technical and Institutional Options for the Future* (Washington: National Academy Press, 1992); Connolly, *Op. cit.*. Not only opponents of inherent safety has proposed these kinds of reforms. See, for example, Lester et al., *Op. cit.* and Lester, *Op. cit.*. In fact, some of these reforms are already underway. Organizations like INPO (Institute of Nuclear Power Operations) already try to enhance the operational performance, and hence operating costs of nuclear plants (S.E. Kuehn, ‘Nuclear Power: Once on Top, Can it Climb Back?,’ *Power Engineering*, June 1993, 19-26; Crane, *Op. cit.*, 470; Weinberg, Spiewak, Barkenbus *et al.*, *Op. cit.*, 81-82.)

163 *Cf.* Lester, Driscoll, Golay *et al.*, *Op. cit.*, 25.

164 This box is based on C.D. Andriesse, ‘Ideale reactoren,’ *Elektrotechniek*, 65(1987)9 (1987), 915-919; C.D. Andriesse, ‘Beheerste kernsplijting,’ *Energiespectrum*, juli/augustus 1990, 202-204; H. van Dam, ‘Veilige kerncentrales,’ *Natuur & Techniek*, 60(1992)7, 503-513; H. van Dam, ‘Inherent veilige kernreactoren,’ *Nederlands Tijdschrift voor Natuurkunde*, A56(1990)4, 7-12; H. van Dam, ‘Veilige Kerncentrales,’ *NRC Handelsblad*, 26-9-1989; H. van Dam, ‘De nieuwe kernreactor; Wegwijs in het doolhof van natuurlijke, passieve en inherente veiligheid,’ *NRC Handelsblad*, 6-2-1992; B.Th. Eendebak, ‘Actieve en passieve veiligheidssystemen bij kerncentrales,’ *Energiespectrum*, januari/februari (1988), 6-15; J.J. Feenstra, ‘Kernvragen,’ *Energie- en Milieuspectrum*, 6/7 (1993), 15; J.-S. Hoogschagen, *Inherente veiligheid van kerncentrales: redder in nood of fopspeen?; Meningen van opinieleiders* (Putten: ECN, 1993), Report nr. ECN-I--93-041; W.H. Houtsma, ‘EZ zit de laatste tijd meer op een laag pitje,’ *Wetenschap & Samenleving*, 44(1992)2, 21-24; G. Kelfkens, *Inherente veiligheid in perspectief* (Zoetermeer: Ministerie van Volksgezondheid, Ruimtelijke Ordening en Milieubeheer, 1994); *Energiespectrum*, november/december (1990), 304-308; C.C. Park, *Chernobyl; The Long Shadow* (London and New York: Routledge, 1989), 138-183; C. Schuuring, ‘Flarden mist omhullen nieuwe kerncentrales,’ *Wetenschap & Samenleving*, 43(1991)1, 47-53.

165 The subsection is mainly based on Kelfkens, *Op. cit.*.

166 This box is based on the literature cited in note 176 and note 177 and on Kelfkens, *Op. cit.*.

167 In this report, they were, presented as possible alternatives in case Advanced LWRs would not be able to regain support from the utilities and the public. This report also recognized the modular Liquid Metal Fast Breeder Reactor (LMFBR) as a possibly inherently safe design (Lester, Driscoll, Golay *et al.*, *Op. cit.*, 18). According to the report, this reactor, however faced economical and political (proliferation) problems.

168 Lester, Driscoll, Golay *et al.*, *Op. cit.*, iv.

169 A small liquid metal breeder reactor was mentioned as a possibility for funding too.

170 This table and the description below on reactor development are based on Forsberg & Weinberg, *Op. cit.*, Hoogschagen, *Op. cit.*, 1.43-1.50; W. Bürkle, 'Weiterentwicklung von Leichtwasserreaktoren,' *Atomwirtschaft*, August/September 1992, 404-409; O. Gremm & S. Jacke, 'Entwicklungspotential und Entwicklungsprobleme neuer Reaktor-Konzepte,' *Atomwirtschaft*, Januar 1992, 22-27; W. Hess, 'Strategische Wende,' *Bild der Wissenschaft*, (1995)1, 32-39; P.E. Juhn & J. Kupitz, 'Nuclear Power Beyond Chernobyl; A Changing International Perspective,' *IAEA Bulletin*, 38(1996)1, 2-9; P. Laklo, *Safety and Economics of New Generations of Nuclear Reactors* (Petten: ECN, 1991), ECN Report No. ECN-I--91-028; L. Kabanov, J. Kupitz & C.A. Goetzmann, 'Advanced Reactors; Safety and Environmental Considerations,' *IAEA Bulletin*, 34(1992)2, 32-36; L. Kabanov, 'Future Nuclear Power Plants: Harmonizing Safety Objectives,' *IAEA Bulletin*, 37(1995)4, 12-15; J. Mattern, 'Fortgeschrittene Siedewasserreaktor-Konzepte,' *Atomwirtschaft*, August/September 1991, 384-387; D. Rittig, 'Sicherheitsaspekte künftiger Leichtwasserreaktoren,' *Atomwirtschaft*, Juli 1992, 352-358. Not all types of reactors under development or research are described below, only what seems to be the most important ones.

171 An example is the Advanced Light Water Program of the US utilities united in the Electric Power Research Institute (EPRI). This program was launched in the early eighties and included the formulation of design requirements for so-called Evolutionary Advanced LWRs (also called first generation advanced LWRs) as well as for Passive Advanced LWRs (also called second generation designs). The latter incorporate some of the passive safety systems advocated by the proponents of inherent safety, but they are *not* the radical departure from current technology advocated by most inherent safety enthusiasts (*Power Engineering*, June 1993, 19-26; Laklo, *Op. cit.*).

172 *Nucleonics Week*, 1 December 1994, 7.

173 For some of the common safety characteristics of these reactors see Forsberg & Weinberg, *Op. cit.*, 140-141.

174 *Intermediair*, 32(1996)17, 13.

175 *Ibid.*.

176 Description of (work on) the PIUS is based on K. Hannerz, L. Nilsson & C. Sundqvist, 'Pius; A New Generation of Water Reactors,' *Nuclear Europe Worldscan*, (1990)11-12, 18-19; Lester, *Op. cit.*, 29; Forsberg & Weinberg, *Op. cit.*, 144-147; Spiewak & Weinberg, *Op. cit.*, 445-450; Weinberg, Spiewak, Barkenbus *et al.*, *Op. cit.*, 39-43 and 256-313.

177 Description of (work on) the MHTGR and HTR-M is based on Agnew & Johnston, *Op. cit.;* Charles, *Op. cit.*; Forsberg & Weinberg, *Op. cit.*, 147-148, Harms *et al.*, *Op. cit.;* Lester, *Op. cit.*, 29; Lidsky, *Op. cit.*; H. Reutler & G.H. Lohnert, 'The Modular High-temperature Reactor,' *Nuclear Technology*, July 1983, 22-30; Weinberg, Spiewak, Barkenbus *et al.*, *Op. cit.*, 43-46 and 314-368; *Intermediair* 32(1996)17, 13 and *Volkskrant*, 29-6-1996.

178 *Nucleonics Week*, 8 April 1993, 5-6.

179 Committee on Future Nuclear Power Development, Energy Engineering Board, Commission on Engineering and Technical Systems, National Research Council, *Nuclear Power; Technical and Institutional Options for the Future* (Washington: National Academy Press, 1992), vii.

180 *Ibid.*, 9.

181 There are some exceptions were inherent safety is explicitly defined as a new design approach or philosophy. *Cf.*, for example M. Cumo, 'A Proposed New Direction in the Development of Nuclear Energy,' *International Journal of Global Energy Issues*, 7(1995)1/2, 31-33.

182 Kabanov, *Op. cit.*; *Convention on Nuclear Safety,* International Atomic Agency Information Circular, Unofficial electronic edition, drawn from internet http://www.iaea.or.at/worldatom/glance/legal/inf449.html, article 18.

183 Barkenbus, *Op. cit.*, 7; Hoogschagen, *Op. cit.*; Kelfkens, *Op. cit.*.

184 C. Flavin, A. Froggatt, A. Kondakji, *et al.*, *The World Nuclear Industry Status Report 1992* (drawn from Internet) (London, Paris, Washington: Greenpeace International, WISE-Paris, Worldwatch Institute, 1992).

8

Discussion and Conclusions

I started this thesis with being puzzled by the combination of continuity and change inherent to technological development. Inertia in technological development becomes problematic when technologies have societally or ecologically harmful effects. Changing the design of technology to take away undesirable effects may then be difficult. While being motivated by such political and societal concerns, the main aim of this thesis is scholarly, to understand continuity and change in technological development.
I chose to study processes of technological change from a particular angle, that of outsider involvement. More specifically, I researched how technological regimes can be transformed due to feedbacks from their environment. This requires studying processes of transformation against the backdrop of existing structural arrangements, like the innovation patterns of technological regimes. To trace empirically the impact of these innovation patterns, I selected my cases so as to represent different innovation patterns.
The two research questions I posed related to impact of the four innovation patterns on processes of transformation and to the mechanisms and routes playing a role in processes of transformation. These questions were by and large answered in Chapters 4 through 7. Comparing the cases, however, allows for additional conclusions and contributes to the general insight in the dynamics of processes of transformation. This also allows me to articulate my contributions to technology studies.
This chapter starts with a discussion of the answers given to the research questions in the Chapters 4 through 7. On the basis of this discussion, some additional conclusions will be drawn. The discussion of the second research question in Section 8.1 amounts to an analysis of the dynamics of processes of transformation that is elaborated in Section 8.2 on the basis of my empirical data, my conceptual framework and some additional literature. The final section discusses the contributions to technology studies.

8.1 Answering the Research Questions

The conclusions of the empirical chapters discussed the questions concerning the impact of existing innovation patterns on processes of transformation and the mechanisms and routes that play a role in processes of transformation, but specifically for the cases at hand and the innovation pattern that they were instances of. In this section, I will put these findings together and see what answers they provide to the main research questions. In fact, they also provide answers to other questions. In particular, they allow me to discuss two sets of hypotheses which provided the starting point of my research design.
The first hypothesis was that the four different innovation patterns enable and constrain processes of transformation differently. This hypothesis was supported by my data as shown in the empirical chapters and summarized in Table 8.1. This finding can be generalized because I selected my cases as to be able to test this hypothesis and answer the first research question. So, following Yin (1989), replication may be claimed. The empirical results confirm my hypothesis and there

are analytical grounds to generalize this finding.[1] On the basis of my research, however, the possibility that there are other relevant innovation patterns than the four I distinguished cannot be excluded.

A second set of hypotheses derives from the fact that I studied Boudon-type processes of transformation. The first hypothesis is that feedbacks from the environment can result in a transformation of the prior existing regime. This hypothesis is supported by my empirical data. I studied cases in which feedbacks from the environment were made manifest. In all studied cases, this eventually resulted in transformation of the prior existing regime. My cases suggest that there is

Table 8.1 *Opportunities and Constraints Inherent to the Four Innovation Patterns*

	Opportunities	Constraints
Supplier-dependent innovation pattern	• Suppliers proactively develop technical alternatives that enable a number of subsequent steps resulting in the transformation of the existing technological regime	• Lock-in in specific products or technological trajectories defined by R&D capacities of suppliers
User-driven innovation pattern	• Changing functional requirements of users directly influence development of technical alternatives and may directly give possibilities for involvement outsiders via a demand;	• Users often have a short-term focus, so little proactive development of technological alternatives • Little room to develop technical alternatives independent from establishment of new functions
Mission-Oriented innovation pattern	• Changing missions directly influence development of technical alternatives and may directly give possibilities for involvement outsiders via a demand (*cf.* user-driven) • New missions may relatively effectively be implemented • Mission actors have a long-term perspective and may undertake or commission proactive development of technological alternatives	• One or limited number of actors control formulation of missions and may effectively block development of technical alternatives and reformulation of mission • Little room to develop technical alternatives independent from establishment of new functions
R&D-dependent innovation pattern	• Researchers proactively develop technical alternatives that enable subsequent steps (*cf.* Supplier-dependent) • Transformations can be integrated in next generation designs • High rate of technological change	• Technological fix (also opportunity)

a link between feedbacks from the environment and transformation of the prior existing regime, but they also show that the first is not a sufficient condition for the latter. This is in line with what I supposed in Chapter 1. The second hypothesis is that outsiders are the ones who make manifest feedbacks from the environment. This hypothesis cannot be tested on the basis of my research because I studied Boudon-type processes of transformation from the angle of outsider involvement. One of the criteria for the selection of my cases was that a process of transformation had to be initiated because outsiders succeeded in making feedbacks from the environment manifest. My research shows that outsiders can make feedbacks from the environment manifest, but it cannot be concluded that it are necessarily outsiders who do so. The third hypothesis is that aggression and demand are the main mechanisms by which feedbacks from the environment can be made manifest. This hypothesis is confirmed by my empirical research as summarized in Table 8.2. Most cases show a combination of aggression and demand, but also in cases that only

Table 8.2 *Aggression, Demand and Transformation of the Technological Regime*

	Aggression	Demand	Transformation
Household refrigerators	Societal groups Concerned scientists	-	Environmental sustainability as new/more important design criterion
Paint	Societal groups Concerned scientists	(University researchers)	Environmental sustainability as new/more important design criterion
Chicken husbandry systems	Societal groups Concerned scientists	Ethologists	More stringent requirements for battery cages (Development alternative systems)
Sewage treatment plants	-	Microbiologists Biotechnological Researchers	Acceptance of microbiological design parameters; partly acceptance of biotechnological innovations
Coastal barriers	Societal groups Concerned scientists	Ecologists Biologists	Integrated water management as partly accepted new guiding principle
Waterside banks	Societal groups Concerned scientists	Ecologists Biologists	Integrated water management as partly accepted new guiding principle
Aero-engines	Societal groups	Aeroacoustic researchers	Noise as design criterion
Nuclear reactors	Societal groups Concerned scientists	Inherent safety advocates (maverick nuclear researchers)	Inherent safety intended as technical feature of next-generation designs

show aggression (household refrigerators) or only demand (sewage treatment plants), a process of transformation was initiated, eventually resulting in a transformation of the prior existing regime. These findings can be summarized by saying that Boudon-type processes of transformation can result in transformation of the prior existing regime, that it can be outsiders who make manifest feedbacks from the environment and that - if outsiders do so - aggression and demand will be main mechanisms. These findings can be analytically generalized because they are in line with my conceptual framework. However, the possibility that other dynamics or mechanisms exist that can result in transformation of technological regimes cannot be excluded.

The discussion of the hypotheses shows two important limits of the analytical generalizibility of my findings. First, my findings cannot be generalized to technological regimes with an innovation pattern that deviates from the four that I distinguished. Second, my findings are restricted to Boudon-types of processes of transformation. (Nevertheless, good reasons exist to suppose that the mechanisms aggression and demand are generally important for the transformation of technological regimes as I will argue in Section 8.3).
Further, the nature of the technologies researched sets limits to the generalizibility of my findings. I selected technological regimes at the level of artefacts. So, my findings cannot be readily generalized to technological regimes at the level of components, devices or systems.[2] In technological regimes at the level of components, standardization will presumably be more important than in the cases I researched because such regimes usually deliver their products to several technological regimes at the level of devices or artefacts. Moreover, component producers will try to profit from economies of scale and this requires a certain degree of standardization. Devices will usually be more application-specific than components, but more standardized than artefacts. For technological regimes at the level of systems, finally, the existing social and technical infrastructure will be more important than in the cases I researched.[3] For distributed systems or networks, so-called network externalities are important. Network externalities imply that there are increased returns to adoption, resulting in path-dependencies and a tendency to one ‘winning’ product or standard.[4] Network technologies like information and communication technology are characterized by strong network externalities. Technological regimes at the level of components, devices and systems will enable and constrain processes of transformation, but not in ways identical to the regimes I studied. With respect to the manifestation of feedbacks from the environment and the mechanisms of aggression and demand, there will be less difference. One difference may be that the aggression of distributed systems or network technologies is more difficult to make manifest because it may be difficult to attribute harmful (secondary) effects to a particular part of the network.
In addition to the hierarchical structuring of technology (components, devices, artefacts, systems), there is the customary distinction between process innovation and product innovation that is relevant for the generalizibility of my results. Utterback (1994) uses the distinction to claim that these have different dynamics and organizes his book in this way. The approach with the help of innovation patterns has advantages over this customary dichotomy because it shows how innovations are

located differently. Moreover, it is not limited to saying that user-driven innovation patterns have a focus on product innovation, and supplier-driven innovation patterns a focus on process innovation: this may happen, but is not necessary.
Other common categorizations are market versus nonmarket, and government-regulated versus not regulated. Stoelhorst (1977) uses these categories to discuss the generalizability of the findings of his case study, and with reason, because his primary interest is in a theory of firms which compete under conditions of technological change. Interestingly, my cases show hybrid situations, with market and nonmarket components, and with explicit regulation as well as diffuse legitimation pressures. Thus, my findings may not apply to situations with only (and strong) market competition, and no regulation. One can argue, however, that such situations are increasingly rare in our modern world.

First Research Question; The Impact of the Innovation Patterns on Processes of Transformation

Processes of transformation take place against the backdrop of existing structural arrangements, like the innovation patterns of technological regimes. Different innovation patterns enable and constrain processes of transformation in different ways as specified in Table 8.1. The case studies show that it was especially the development of technical alternatives during a process of transformation that was enabled and constrained by the existing innovation pattern. Due to constraints inherent in the four innovations patterns, technical alternatives were sometimes developed in protected spaces outside the existing technological regime. I have noticed this phenomenon at several places in the case studies. Now that an overview over all cases is available, it can be put in context.

Table 8.3 summarizes which actors were involved in the development of technical alternatives during processes of transformation and what the typical source or mechanism for the development of these alternatives was. By comparing these findings with Table 2.2, and Tables 3.2 through 3.5 which define the same variables for the existing innovation patterns, several things become clear.
First, in the regimes with an R&D-dependent innovation pattern (aero-engines, nuclear reactors), the development of technical alternatives was in line with this innovation pattern. The existing innovation pattern, as it were, absorbed the external input, resulting in a transformation of the prior existing technological regime.
Second, there are a number of cases in which the development of technical alternatives partly reflected the existing innovation pattern and partly deviated from it. For paints and household refrigerators, both regimes with a supplier-dependent innovation pattern, some technical alternatives (HFC 134a, low-organic synthetic paints) were developed according to the existing innovation pattern, while others (Greenfreeze, natural paints) were developed in protected spaces independent from the existing regime and its innovation pattern. In the case of coastal barriers (mission-oriented innovation pattern), technical alternatives were developed according to the existing innovation pattern, although the proposal of such alternatives started before the mission of the regime was reformulated. In the case of waterside banks (mission-oriented innovation pattern), the development of technical

alternatives started in response to local missions, somewhat independent of the existing innovation pattern. Later, technical alternatives were (further) developed in the line with the mission of the entire regime which by then had been reformulated. Third, I have two cases in which the development of all technical alternatives took place in protected spaces independent of the existing technological regimes and their

Table 8.3 *Development of Technical Alternatives*

	Technical alternative	Actors involved in development	Typical source/mechanism of innovation
Paints	Synthetic paints with a lower VOC content	*Suppliers* Paint manufacturers (Industrial users)	*Raw materials (component parts)* (Expectations)
	Natural paints	Producers of natural paints	New guiding principle (Protected space)
Household refrigerators	(refrigerators with) HFC 134a	*Suppliers* (Refrigerator firms)	*Component part* (Expectations)
	Hydrocarbons (Greenfreeze)	DKK Scharfenstein (Dortmund Doctors) (Greenpeace)	Design criterion (Protected space)
Chicken husbandry systems	Scratching systems	Existing system	Existing system
	Aviary	Research institutes like *Spelderholt* (Producers of chicken husbandry systems)	Design Criterion (Protected space)
Sewage treatment plants	Various (sub)systems, e.g. for biological phosphate removal	Biotechnological researchers (Engineering firms)	(Biotechnological) design approach (Protected space)
Coastal barriers	Storm surge barrier Oosterschelde	(Studiegroep Zeeuws Meer) DOS-bouw (later) *Rijkswaterstaat*	*Mission*
Waterside banks	Various ecologically sound bank constructions	Researchers (*Project 'Ecologically sound banks*) Engineering firms Building contractors	*Mission* (first local in protected spaces related to local missions)
Aero-engines	More silent aero-engines	*R&D institutes* (a.o. NASA) aero-engine producers	*Integrated in next generation design (expectations)*
Nuclear reactors	Inherently safe reactors (PIUS, MHTGR)	*R&D institutes* from various countries reactor vendors	*Integrated in next generation design (expectations)*

innovation patterns. These were the cases chicken husbandry systems and sewage treatment plants. Both technological regimes had a user-driven innovation pattern. How can these differences between the cases be explained? One possible explanation is differences in the ease with which the existing technological regime can be transformed. For an important part, this ‘ease’ will depend on the innovation pattern of the existing technological regime. On the basis of the empirical findings summarized in Table 8.1, three categories of innovation patterns can be distinguished that differ in the degree to which they enable, and constrain, the transformation of a prior existing technological regime. The first category consists of the R&D-dependent innovation pattern. This pattern enables the transformation of a prior existing technological regime in several ways, while it has only a few constraints for processes of transformation. The second category consists of the supplier-dependent and the mission-oriented innovation pattern. Both patterns are characterized by several opportunities and constraints for processes of transformation, which are more or less in balance. The third category consists of the user-driven innovation pattern. This pattern is the most constraining for processes of transformation.

If we set out the degree to which the existing innovation pattern eased transformation of the prior existing technological regime against the degree to which technical alternatives were developed according to that innovation pattern, we get Table 8.4. This table shows a correlation between both variables. Processes of transformation will be more similar to existing innovation patterns, *i.e.* technical alternatives will be developed according to the existing innovation pattern, the more the latter enable the transformation of the prior existing technological regime.

This correlation can be better understood by looking at the specific ways in which

Table 8.4 *Relations Between Constraints of the Innovation Patterns and Deviations From the Innovation Pattern During Processes of Transformation*

Degree to which process of transformation was shaped by existing innovation pattern (measured by developed technical alternatives)	Degree to which existing regime (innovation pattern) enabled transformation		
	- (User-driven)	+/- (Supplier-dependent and Mission-oriented)	+ (R&D-dependent)
-	Chicken Husbandry Systems Sewage Treatment Plants	Coastal Barriers	
+/-		Household Refrigerators Paints Waterside Banks	
+			Aero-engines Nuclear Reactors

the different innovation patterns enable and constrain processes of transformation. An important difference between the four innovation patterns is the presence of actors with a long-term perspective that proactively undertake the development of technical alternatives. Proactive development of technical alternatives takes place before strived-for-changes reach the agenda of the entire technological regime and new definitions of the central elements of the regime become shared. Proactive development of technical alternatives thus takes place in anticipation of changes in the central elements of the technological regime. In this way, technical alternatives can be developed that do not fit the existing technological regime in all respects. Subsequently, these alternatives enable the reformulation of the central elements of the regime. They do so because they show that a new alignment between functions and technical configurations is possible. Moreover, they create alternative courses of action for the actors involved, so enabling the routes of regulation and user pressure through which the regime can be transformed. This dynamics is clearly visible in cases like household refrigerators, paints and aero-engines, in which the existing regime was characterized by either a supplier-dependent or R&D-dependent innovation pattern. Here, the proactive development of technical alternatives enabled the route of regulation through which the existing technological regime was transformed.

In the mission-oriented cases (coastal barriers and waterside banks), we saw less proactive development of technical alternatives. This was, however, compensated by the fact that mission actors, by being active at the global level of the regime, had a long-term perspective and were in a relatively good position to transform the regime deliberately. Due to their long-term perspective, they were more sensitive to developments outside the technological regime than individual users in the user-driven innovation pattern. This means that they will occasionally undertake or commission the proactive development of technical alternatives, for the case that transformation of the regime might turn out to be 'unavoidable.'

In a user-driven innovation pattern, there will be less proactive development of technical alternatives because long-term developments and developments outside the regime are often beyond the horizon of users. There is little room to develop technical alternatives that do not fit the existing regime. In the studied cases, these constraints were overcome by developing technical alternatives in protected spaces independent from the existing regime. So the constraints, inherent in the user-driven innovation pattern, as it were, forced actors that wanted to transform a technological regime to develop technical alternatives in protected spaces.

To explain the differences between the R&D-dependent innovation pattern on the one hand and the supplier-dependent and mission-oriented innovation pattern on the other hand, it is not enough to refer to the proactive development of technical alternatives. Here, the explanation can be found in the high rate of technological change characteristic of the R&D-dependent innovation pattern and the fact that in this pattern innovation often takes place in successive generations. Especially the latter characteristic makes it possible to incorporate new technical features - deviating from the existing technological regimes - in next-generation designs. This happened in both the aero-engine and nuclear reactor story. These cases show that in the R&D-dependent innovation pattern, technical alternatives departing from the existing regime cannot only be developed proactively but can also be planned as next-generation designs. Therefore, this pattern is more enabling for the development of technical alternatives not fitting the current regime than the supplier-dependent and mission-oriented innovation pattern.

The four innovation patterns thus differ in the degree to which they allow for the development of technical alternatives not fitting the existing regime. In the R&D-dependent innovation pattern, there is proactive development and the possibility to incorporate transformations in next-generation designs. In the supplier-dependent, there is proactive development in anticipation of transformation. In the mission-oriented innovation pattern, there are mission actors on the global level with a long-term perspective that, to some extent, are able to transform the regime deliberately via reformulating the mission and that can undertake or commission the proactive development of technical alternatives. In the user-driven innovation pattern, finally, there are few possibilities to develop technical alternatives not fitting the current regime.

What the cases further suggest is that constraints in the existing innovation pattern to develop technical alternatives will be circumvented by developing technical alternatives in protected spaces. Of course, this is no necessity. The process of transformation might also have stopped. However, the cases suggest that actors who want to transform a regime will be looking for alternative ways to develop technical alternatives and that protected spaces are a main way in which they do so. This explanation is supported by the fact that, in the cases, a direct relation existed between constraints inherent to the four innovation patterns and the development of particular technical alternatives in protected spaces. The Greenfreeze and natural paints were developed in protected spaces because they did not fit the current R&D trajectories and interests of suppliers (supplier-dependent innovation pattern), the aviary and biotechnological waste water treatment installations were developed in protected spaces because they did not fit current functional requirements of users (user-driven innovation pattern) and the first ecologically sound banks were developed in local protected spaces because they did not fit the mission of the entire regime (mission-oriented innovation pattern).

Technical alternatives developed in protected spaces may help to transform a technological regime if they are accepted by users and other actors in the regime. In that case, the technical alternative begins to function as an *exemplar* of a new alignment between functions and technical configurations, resulting in a reformulation of the rules of the regime.[5] That this is possible is due to the ‘mobility’ of technical alternatives: they can be adopted independently from their origin.

In the case studies, we see this dynamics in the case of the Greenfreeze. This alternative technology functioned as exemplar for a new alignment between functions and technical configurations, bringing some changes in the rules in the household refrigerator regime but not changing the supplier-dependent innovation pattern. The other technologies developed in protected spaces (natural paints, alternative housing systems for poultry, biotechnological treatment installations) were only accepted by a limited number of users and other regime insiders. They are now used in market niches. Their existence nevertheless puts some pressure on the existing regime to improve its products and to forestall that more users and other actors begin to prefer the alternative technologies.[6]

The analysis can be taken a step further by looking at an additional point: structural changes in the innovation pattern of a technological regime as a result of a process of transformation. In most of my cases, the existing innovation patterns were not changed during the studied processes of transformation. Only in two cases, some changes in the existing innovation pattern did take place.
One was the technological regime of paints (Chapter 4). This regime initially had a supplier-dependent innovation pattern. Fundamental research is, however, increasingly becoming a more important source of innovation. This is related to the process of transformation and to constraints inherent to the existing innovation pattern. Paints with no or fewer VOCs required new scientific insights which suppliers and paint companies did not have in-house immediately. In the case, this resulted in an increase in R&D. Especially the larger paint manufacturers increased their R&D efforts and intensified their contacts with the universities. This brought a shift in the existing innovation pattern, but not a dramatic one. The existing innovation pattern by and large remained supplier-dependent.
The other case in which a shift in the innovation pattern can be seen is waterside bank constructions. Here, the initial innovation pattern was mission-oriented with some user-driven characteristics. Over time, the innovation pattern became more mission-oriented because local water administrators were forced to comply with central policy, and thus with centrally formulated missions. In this case as well, the shift in innovation pattern was related to the process of transformation and constraints in the initial innovation pattern. The autonomy of local water administrators constrained the implementation of integrated water management as a new mission. In response, the central government wanted these local water administrators to comply with centrally formulated missions.
These two examples show that the innovation pattern of a technological regime can be changed during a process of transformation, especially when the innovation pattern constrains the process of transformation. In literature as well, examples of changing innovation patterns can be found.[7] Still, my cases suggest that technological regimes will be transformed more often and on shorter time-scales than innovation patterns. This is understandable because innovation patterns constitute the structure of the interaction system in which the technological regime is embedded. This structure consists of the interdependencies and role-relations between the actors. Within this structure, different rules-sets or technological regimes can be embedded. Therefore, a technological regime can change without a change in the innovation pattern in which it is embedded. Main ways in which this can happen are by the proactive development of technical alternatives not fitting the existing regime entirely, the incorporation of transformations in next-generation designs and the development of technical alternatives in protected spaces.
The reason why innovation patterns change on longer time-scales than technological regimes must be sought in the fact that interdependencies and roles are more difficult to change than the specific rules that guide the design and further development of new technologies. Especially if new alignments between configurations and

functions can be brought about, rules may change relatively easily and without a change in the innovation pattern, the structure, of the technological regime. Even if radical new alignments between functions and technical configurations - what Clark, Abernathy and Utterback call 'architectural innovations'[8] - require alignment with new users or the entry of new firms, the interdependencies and role-relations between the actors are not necessarily changed. New actors may fill the 'slots' left open by the old actors who are now no longer part of the interaction system in which the technological regime is embedded. This may happen without a fundamental change in the interdependencies and role-relations, the structure of the interaction system.

Table 8.5 *Pattern for Aggression*

	Elements of triangle of technological development	Actors	Permanent/ temporarily role for actors
Household refrigerators	Secondary effects translated into new design criterion	Societal groups Concerned scientists	Temporary
Paints	Secondary effects translated into new design criterion	Societal groups Concerned scientists	Temporary
Chicken husbandry systems	Secondary effects translated into new requirements	Societal groups Concerned scientists	Permanent (in protected spaces for alternative systems)
Sewage treatment plants	-	-	-
Coastal barriers	Secondary effects translated into new guiding principle	Societal groups Concerned scientists	Temporary (Some critical scientists permanent via demand)
Waterside banks	Secondary effects translated into new guiding principle	Societal groups Concerned scientists	Temporary (Some critical scientists permanent via demand)
Aero-engines	Secondary effects translated into new design criterion	Societal groups	Temporary
Nuclear reactors	Secondary effects translated into new requirements and technical features	Societal groups Concerned scientists	-
General Pattern	*Secondary effects translated into new requirements, design criteria or guiding principles*	*Societal groups* *Critical scientists*	*Temporary*

Second Research Question; Mechanisms and Routes for Transformation

To understand how processes of transformation start, I adopted and extended the sociological theory of Boudon. This resulted in the hypothesis that processes of transformation can set off either because of aggression toward the environment or a demand upon the environment, or a combination of both. In my cases, the

Table 8.6 *Pattern for Demand*

	Elements of triangle of technological development	Actors	Permanent/ temporarily role for actors
Household refrigerators	-	-	-
Paints	● Development design tools	Outsider or marginal professionals	Permanent
Chicken husbandry systems	● Operationalization design criteria	Outsider or marginal professionals	Permanent (in protected spaces for alternative systems)
Sewage treatment plants	● Operationalization design criteria ● Development design tools ● (New guiding principle, design approach)	Outsider or marginal professionals	Permanent
Coastal barriers	● Operationalization design criteria ● Development design tools ● New guiding principle, design approach	Outsider or marginal professionals	Permanent
Waterside banks	● Operationalization design criteria ● Development design tools ● New guiding principle, design approach	Outsider or marginal professionals	Permanent
Aero-engines	● Development design tools	Outsider or marginal professionals	Permanent
Nuclear reactors	● (New guiding principle, design approach)	Outsider or marginal professionals	Permanent (?)
General Pattern	*Three ways of involvement:* *● Operationalization design criteria* *● Development design tools* *● New guiding principle, design approach*	*Outsider or marginal professionals*	*Permanent*

manifestation of aggression and demand were the mechanisms by which processes of transformation were initiated. With each case of aggression or demand, made manifest by outsiders, a transformation of the existing technological regime could be associated (Table 8.2). On the basis of my cases, general patterns can be distinguished with respect to the mechanisms of aggression and demand (Table 8.5 and 8.6).

As Table 8.5 shows, aggression of existing technological regimes was in all cases made manifest by societal groups and/or critical scientists. They could do so because the regimes produced secondary effects disliked by a significant number of actors outside the existing technological regime and attributable to that regime. A main way in which outsiders made aggression manifest was by delegitimizing the outcomes of the existing regime and so mobilizing other actors.[9] In the cases, the manifestation of the aggression of the existing technological regime resulted in the feedback of particular secondary effects to that regime and their translation into new requirements, design criteria or guiding principles. This happened via the routes of delegitimation, user pressure and regulation.

In all cases of a demand upon the environment, outsider or marginal professionals acquired a more permanent or even central role in existing technological regimes (Table 8.6). In these cases, outsider or marginal professionals initiated the manifestation of the demand upon the environment. They could do so because the existing technological regime was characterized by certain internal (engineering) problems or tensions. Occasionally, they could convince other actors of the need of particular changes in the regime, for example the need to use other design tools. In all cases, outsider or marginal professionals acquired a more permanent place in the existing regime due to the specialized knowledge they possessed. They did so in three ways: 1) via design criteria and their translation into more specific requirements and specifications, 2) via the development of (new) design tools like technical models and design parameters and 3) via the effectuation of new guiding principles or design approaches that allocated new roles to existing and new professional experts.

Thus, aggression and demand are mechanisms for the initiation of processes of transformation. They offer outsiders, together with other actors, the possibility to make feedbacks from the environment of a technological regime manifest. Whether this manifestation will result in a transformation of the prior existing technological regime depends on other mechanisms than aggression and demand. This is why I posed the second research question in a broader manner. What are these routes or mechanisms via which technological regimes are transformed in the case of aggression toward the environment or in the case of a demand upon the environment?

With respect to aggression, I found three specific routes: regulation, user pressure and delegitimation. The latter functioned as a delegitimation detour for the other two routes and as a way to redefine directly the guiding principle of a technological regime or other central elements of the regime.[a] With respect to demand, I found one route: the involvement of initially outsider or marginal professionals. So, my cases show four specific routes via which technological regimes are transformed: delegitimation, regulation, user pressure and the involvement of initially outsider professionals.

The identification of these four routes, however, only provides a first-order answer to the second research question. The cases reveal a dynamics of processes of transformation that is far more complex than can be grasped with these four routes. Take for example the involvement of initially outsider professionals. On the basis of my empirical results, it can be argued that the success of this route will depend on the degree to which new definitions of design approaches and guiding principles become generally accepted in the regime. This becomes clear if one compares the case studies on coastal barriers and waterside banks on the one hand with the case study on sewage treatment plants on the other hand (Chapter 5 and 6). In the first two cases, new design approaches and guiding principles that allocated new roles to initially outsider professionals were more generally accepted than in the case of sewage treatment plants. Consequently, ecologists and biologists could more successfully acquire a role in the regime of coastal barriers and waterside banks than biotechnological researchers and microbiologists in the regime of sewage treatment plants. The successful involvement of initially outsider professionals thus depends on processes of *technical agenda building*, the process by which the elements of the triangle of technological development are redefined and become shared in technological regimes.[10] Such processes of agenda building took place in fora like the CUR (waterside banks) and the STORA (sewage treatment plants).

Through processes of agenda building, the central elements of technological regimes can be redefined and new alignments between functions and technical configurations can be achieved. The process of agenda building is, however, not enough to achieve new alignments between functions and technical configurations. To achieve such new alignments successfully, also actual artefacts, technical alternatives have to be developed that embody such new alignments. This *development of technical alternatives* must be seen as an additional factor. While guided by processes of agenda building, it has its own status. First because even when actors agree on the specifications and technical features an artefact has to meet, no guarantee exists that the artefact actually designed and produced will have the desired properties. As argued in Chapter 1, artefacts are best conceived as imperfect embodiments of requirements and specifications. Because not all requirements can be met at once, compromises or tradeoffs among the requirements have to be accepted. A typical example is the aviary (Chapter 4). This alternative housing system for laying hens could not meet all requirements that had been formulated for it. If it had been as 'efficient' as the battery cage, as was the intention of its designers, it would probably have been adopted on a larger scale by poultry farmers. The new alignment between

a In Chapter 6, I also distinguished reformulation of the mission as a fourth route. This route is unique to regimes with a mission-oriented innovation pattern and can be seen as a combination of the routes of user pressure and regulation because governmental bodies combine the roles of users and regulators in such innovation patterns.

technical configurations and functions that was planned could not be achieved because that alignment was technically not feasible.
The second reason why the development of technical alternatives has a status of its own is that it is not necessary that definitions of the central elements of technological regimes have stabilized before the development of (new) artefacts starts. Rather, there is partial stabilization of the central elements of a technological regime, for example within a firm or among the suppliers in a technological regime. Then we have the development of technical alternatives and next we have debates over the (non-)acceptance of these artefacts. This is clearly visible in the cases. Especially in the regimes with a supplier-dependent and an R&D-dependent-dependent innovation pattern, we saw that technical alternatives were developed proactively, *i.e.* before the development of such alternatives became an item on the agenda of the entire technological regime and debates about the (non-)acceptance of these alternatives started.

The development of technical alternatives is crucial for processes of transformation because only by developing concrete artefacts it becomes clear whether an intended new alignment between functions and technical configurations is technically feasible. In addition, the *availability* of technical alternatives will influence the dynamics of processes of transformation. In Chapter 4, the potential success of the routes of regulation and user pressure depended on the availability of technical alternatives and their specific properties. Differences in the available alternatives between the household refrigerator case and paint case (partly) explained differences in the routes of regulation and user pressure between both cases.
In the household refrigerator case, the government depended on chemical suppliers for the development of alternatives to CFCs. Once such alternatives became available, it became more easy for governments to issue regulation and more difficult for refrigerator firms to resist regulation. The development of technical alternatives therefore enabled the route of regulation. In the case of paints as well, the availability of alternatives enabled regulation. Here, however, not for all applications alternatives were available. Moreover, most available alternatives brought tradeoffs among the different requirements for paints which were not easily accepted by the actors involved. Thus, the government depended on the producers and users of paints for the further development and acceptance of alternative paints. In these circumstances, it was more attractive for the government to opt for self-regulation by industry.[11]
The importance of available technical alternatives is very clear for the route of user pressure. In the refrigerator case, Greenpeace needed an alternative refrigerator to mobilize users. For the development of such a refrigerator, Greenpeace depended on industry. Initially, the German refrigerator manufacturers refused to develop a refrigerator with hydrocarbons. When Foron was eventually prepared to do so and the Greenfreeze was developed successfully, this brought an important reversal in the dependency relations between Greenpeace and the refrigerator firms. Greenpeace could mobilize the support of consumers. Fearing a loss of market share, the other refrigerator companies decided to switch to hydrocarbons. In the paints case, environmental groups also tried to mobilize users against the regime with the help of

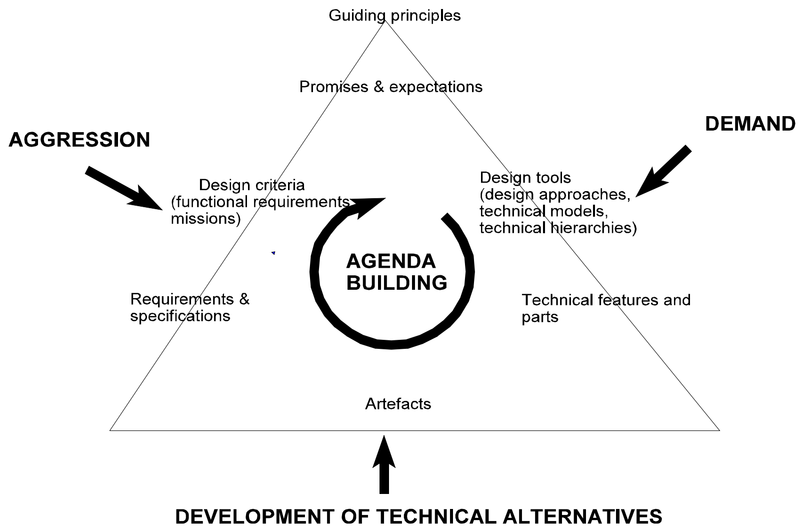


Figure 8.1 *The Triangle of Technological Development*

available alternative paints. Only a limited group of users, however, adopted these alternative paints. In this case, user pressure was hardly a successful route for the transformation of the existing regime.

These examples show that the availability of technical alternatives, and their specific properties are important in two respects. First, technical alternatives enable alternative courses of action for the actors involved. Ultimately, such alternative courses of action may prove attractive even for actors with a high stake in the existing technology. Second, they change existing dependencies between actors. As a result, they can create a new interaction situation that enables a series of actions, ultimately resulting in a transformation of the existing technological regime. In this way, the availability of technical alternatives enables the routes of user pressure and regulation, but also the routes of delegitimation (showing that alternatives are available) and involvement of initially outsiders who may contribute to R&D on, and the design of, the alternative technology.

In the cases, the mechanisms of aggression, demand, technical agenda building and the development of technical alternatives were identified empirically, but they can be related to the concept of 'technological regime' and the triangle of technological development (Figure 8.1). The mechanisms aggression and demand both make manifest feedbacks from the environment, resulting in the formulation of strived-for-changes and proposals for new definitions of the central elements of the regime by a limited group of actors. In the case of aggression, these proposals relate to the left hand of the triangle, in the case of demand to the right hand. Technical-agenda building is the process in which new definitions of the elements of the triangle are debated and translations between them are made, possibly resulting in the sharing of new definitions of these elements. The development of technical alternatives is not only guided by technical agenda building, but also takes place independently of it, through the proactive activities of particular actors (depending on the innovation pattern) and in protected spaces.

8.2 The Dynamics of Processes of Transformation

Four mechanisms play an important role during processes of transformation: aggression, demand, technical agenda building and the development of technical alternatives. In the cases, the importance of these mechanisms changed over time. On the basis of the temporal order that is visible in the cases, three phases may be identified.

In the first phase, feedbacks from the environment are made manifest through the mechanisms of aggression and demand. In the case of aggression, the regime is characterized by (secondary) effects that are seen as undesirable by particular outsiders. They can make these (secondary) effects manifest by delegitimizing the existing regime and its outcomes. As a result of successful delegitimation, users and governmental bodies may give up their (tacit) cooperation with the existing regime, setting off the routes of user pressure and regulation. In the case of demand, the regime is characterized by internal problems that are made manifest by initially outsider or marginal professionals. The manifestation of internal problems creates opportunities for the closer involvement of these groups in the regime.

In the second phase, technical agenda building takes place. In this phase, strived-for changes, formulated in the first phase, reach the agenda of the entire technological regime and are translated into new definitions of the central elements of the regime. Organizations active at the global level of the technological regime, like branch and professionals organizations, constitute important fora for technical agenda building in this phase.

The third phase can be characterized as the development and acceptance of technical alternatives. Now, technical alternatives are developed proactively, are incorporated in next-generation designs or are developed in protected spaces. If these alternatives are accepted in the regime, they function as an exemplar for a new alignment of functions and technical configurations and so transform the existing regime.

8.2.1 How Latent Feedbacks Become Manifest; Aggression and Demand

Aggression and demand are effectuated by different groups of outsiders and impinge on different elements of technological regimes. In the case of aggression, we have societal groups and critical scientists impinging on the definition of functions and related elements like guiding principles and design criteria. These outsider groups usually do not acquire a permanent place in technological regimes. In the case of a demand, we have outsider or marginal professionals who can acquire a more permanent place in technological regimes due to the specialized knowledge they possess. They usually impinge on elements of technological regimes related to technical configurations and design tools.

Aggression

If a technological regime produces outcomes disliked by regime outsiders, we speak of aggression of that technological regime toward its environment. An example is the ozone layer degrading effect of CFCs (Chapter 4). This effect of CFCs was not taken into account, not even realized, when CFCs were developed and became widely used. So it was a secondary effect. Later, when this secondary effect was discovered, it was interpreted as aggression.

Aggression of technological regimes can be discovered and articulated by regime outsiders. Scientists nowadays play an important role in discovering risks or secondary effects of technology and thus in explicating aggression of technological regimes. According to the sociologist Beck, one characteristic of the 'new' risks in our modern society is that they often cannot be observed without help from the sciences.[12] CFCs are a case in point. Their ozone-degrading capacity was identified by atmospheric scientists and cannot be observed directly.

In the studied cases, scientists not only functioned as early warners and critics of risks and secondary effects produced by technological regimes, they also helped societal protest groups to make their case against such regimes. Sometimes they did do so deliberately, as with ethologists protesting against the neglect of animal welfare in chicken husbandry systems (Chapter 5). However, even if scientists themselves did not object to technological regimes, their findings or statements could be mobilized by social protests groups against particular technological regimes. Nuclear protesters, for example, enthusiastically quoted the words of the nuclear proponent Alvin Weinberg that nuclear energy implied 'a Faustian contract with society.'[13]

The role of scientists in the foundation of societal protests against technological regimes is partly due to the status that science has in today's society as producer of objective knowledge. Often, however, there is scientific controversy about the kind of technological risks and secondary effects produced by technological regimes. Scientists do not agree on such issues as the risks of nuclear power or the actual neglect of animal welfare in battery cages. Of course, in particular controversies agreement may be reached among scientists about the effects and risks of a technology, but such agreement may not be presupposed.

In the cases, social (protest) groups played an important role in further articulating and criticizing aggression of technological regimes. They were, however, neither powerful enough nor technically competent enough to enforce changes in a technological regime in a direct way. They could neither command the designer/producers to design for different functions nor suggest appropriate technical configurations to realize them. Therefore, they had to find some way to mobilize leverage on specific technological regimes so that powerful and knowledgeable actors within them felt compelled to transform their activities, that is to pursue different functions or to mobilize different technical configurations that respond to criticism.[14]

How was such leverage created? In the preceding chapters, I have found three routes along which certain secondary effects were translated into new design criteria or guiding principles: user pressure, regulation and delegitimation. The route of user pressure addresses the designer/producers of a technology via users or the users of users, *i.e.* via what Schwartz Cowan (1987) has called the consumption junctions of a technology. The route of regulation addresses designer/producers via regulators, especially but not exclusively governmental bodies. The route of delegitimation addresses the designer/producer via either the effectuation of new guiding principles or through a delegitimation detour for the other routes.

Social (protest) groups depend on the cooperation of other actors (users, regulators) for the effectuation of the routes of user pressure and regulation or the effectuation of new guiding principles. This cooperation can be achieved via a *delegitimation detour*.[15] In a delegitimation detour, particular technological outcomes and processes are discredited as morally objectionable. Functions or secondary effects of a technology are coupled with the neglect of commonly accepted values. Central to a delegitimation detour then is *rhetorical labeling*, the processes in which particular artefacts, activities or actors are labeled as morally valuable or objectionable.

A whole range of 'conviction devices' can be used for rhetorical labeling such as photos, films, slogans and pamphlets. Examples are a photo of a suffering chicken with the text 'This is a chicken in a battery cage' or an advertisement for a clean well-looking battery cage with the text 'Five star hotel for chickens.' In the first example the battery cage is labeled as detrimental to animal welfare and morally objectionable, while in the second example the battery cage is portrayed as a contribution to animal welfare and morally desirable or at least acceptable.

Sometimes, rhetorical labeling was so effective that technologies got a highly symbolic meaning. A typical example is nuclear energy (Chapter 7). For some opponents of this technology nuclear energy became the icon of the ultimate evil, symbolizing the arrogance of the establishment and one-dimensional materialistic development. For some nuclear proponents, on the other hand, nuclear energy became the icon of progress and freedom.

Rhetorical labeling, and delegitimation in general, cannot be controlled by one actor. Take, for example the protests against the closure of the *Oosterschelde* (Chapter 6) or those against nuclear energy (Chapter 7). In both cases, delegitimation was partly the result of general societal developments beyond the control of individual actors. This included growing doubts about the focus on materialistic progress, a sense of societal and political crisis, growing attention to environmental problems and the emergence of protest movements of students, environmentalists and others.

A delegitimation detour then is best conceived as a *sociological mechanism* in which specific properties or effects of a technology (secondary effects, functions) become coupled to the neglect of commonly cherished values and are labeled as morally illegitimate. The working of this mechanism does not primarily depend on the intentions of the involved actors as can be illustrated by the protests against airport noise (Chapter 7). Local environmental and citizens' groups started protesting against noise annoyance around particular airports in the sixties. Through the campaigns of these groups and media coverage, such protests were translated into more general complaints about aircraft noise and were connected to a neglect of the right of individuals to sleep well at night. Political parties and (local) governments that wanted to show that they took the issue seriously subsequently threatened with measures like night curfews. These measures were disliked by aviation organizations

like airports and airlines, because they detrimentally affected the (long-term) economic prospects of aviation. To avoid such measures, these organizations urged the development of more silent aircrafts. Some immediate measures proved unavoidable, but this in itself gave aviation organizations an extra motive to urge for more silent aircrafts. This in turn led to the development of more silent aero-engines, because the aero-engine was the main source of aircraft noise.
In this example, the actions of certain social (protest) groups were translated into new design criteria in the technological regimes of aircrafts and aero-engines via a complex detour. The exact intentions of the social (protest) groups were hardly important for the overall dynamics of this process. Their protests had an effect, independent from the question whether they aimed at a delegitimation detour, or not.

Delegitimation as such does not change the dependencies as they exist in technological regimes. It can nevertheless be effective in initiating the routes of user pressure and regulation because it gives users and regulators a motive to change their behavior and to give up their tacit cooperation with the designer/producers of a technology. To understand this potential effectiveness of delegitimation, it should be realized that forms of cooperation as they exist in technological regimes are often tacit and based on mutual trust (*cf.* Chapter 2).
The designer/producers of a technology, for example, depend on the tacit cooperation of the government. As Howard Becker has remarked in relation to arts worlds, but as is equally true with respect to technological regimes: '... the government, however little it does, is inescapably an important part of the cooperative art-producing network: since it *might* intervene to prevent the production or distribution of art works, even if it seldom or never does, failure to act is a crucial form of cooperation in artistic activities.'[16] If it wants to, the government can give up such tacit forms of cooperation and try to intervene in technological regimes.
In the same vein, the designer/producers of a technology depend on the users of a technology. Like the dependency of designer/producers on the government, this dependency can be latent. Users buy particular technological products as long as they have a certain general trust in these products and their producers. Especially if users are anonymous consumers, this form of cooperation is tacit. It is not based on explicit agreement between users and designer/producers. Cooperation is based on the consumers' trust in the products and in their producers. When consumers collectively lose this trust - including the case where they shift to a new product - they give up their tacit cooperation by stopping to buy the products. This can happen, for example, when it turns out that a product has adverse health effects.[17]
To convince users that they should give up their tacit cooperation with the designer/producers of a technology, social (protest) groups will try to unblackbox the harmful properties of existing products. Unblackboxing refers to the process in which properties of artefacts that are not directly visible for the users or consumers of a product are made more easily discernable. In the refrigerator story, for example, environmental groups unblackboxed the contribution of the new (HFC 134a) refrigerators to the greenhouse effect (Chapter 4). In the chicken husbandry story, animal welfare groups successfully tried to unblackbox the contribution of different

types of eggs to animal welfare by the introduction of different kinds of stamps for different eggs (Chapter 5).
Unblackboxing is the reverse process of the blackboxing of artefact properties as it takes place during design processes. As Chabaud-Richter (1995) has pointed out, during the design process an inside and an outside for products are created. The inside is hidden from the users - think, for example, of the inside of a washing machine - and is intended to be the domain of engineers, repair people and other technically competent people. The outside is open to the users, the public. During design processes also (potential) secondary effects of products are blackboxed. Unblackboxing these properties of artefacts is an important first step in mobilizing user pressure against particular technological regimes.

If regulators and users/consumers give up their tacit cooperation, this has devastating effects on the chances of survival of particular designer/producers and ultimately of entire technological regimes. Something of these dramatic effects is visible in the controversy over the Brent Spar. Shell's intention to sink down the Brent Spar was heavily criticized by Greenpeace. Greenpeace underlined these protests by several spectacular actions covered by the media. This coincided with the need of political actors, especially in Germany, to make a gesture. Ministers from several European governments spoke out against the plan of Shell. Eventually, delegitimation of the Shell plan was so successful that automobilists in several European countries decided overnight to boycott Shell. Confronted with this sudden loss of trust, and realizing the long-term consequences that such a loss might have, Shell felt forced to revise its earlier decision with respect to the Brent Spar, even while it was not convinced by the arguments of its opponents.
What happens in a delegitimation detour, and what the Brent Spar example illustrates, is that dependencies between the designer/producers of a technology and other actors, which are usually kept latent, become manifest. Tacit cooperation based on mutual trust and legitimacy becomes precarious. Such actors as users, governments, banks, investors and insurance companies are alienated from a technological regime and subsequently give up their tacit cooperation.
This is not to say that delegitimation is in itself enough to break down an existing technological regime. Even if delegitimation is successful and actors begin to consider certain courses of action morally objectionable, they may still have reasons to stick to them. As we have seen in the chicken husbandry story (Chapter 5), poultry farmers to some extent became convinced that keeping chickens in battery cages was less desirable. However, they did not want to change their behavior accordingly given their prior investments in battery cages, their dependency on the egg market and the economic risks that a switch to alternative systems entailed in their eyes. For similar kinds of reasons, the Dutch government decided *not* to ban the battery cage. While it was convinced that keeping chickens in battery cages was undesirable for animal welfare reasons, it did not want to risk the economic and employment benefits of the Dutch poultry sector. Clearly, existing dependencies in a technological regime and in society as a whole can give actors strong motives to stick to certain courses of action, even if they themselves consider such courses

morally undesirable. The perceived costs of giving up the current behavior are simply too high.

Demand

In the case of a demand, regime insiders feel a need for change or the regime is characterized by particular (engineering) problems that cannot be optimally solved by regime insiders alone. This offers outsiders an opportunity to contribute to, and get a role in technological regimes.

Demands upon the environment are often latent: regime insiders do not literally ask particular outsider professionals to make a contribution. In the case studies, outsider professionals made manifest the demands upon the environment. They argued that they possessed knowledge or capacities with which particular problems in a technological regime could be solved.

One reason that technological regimes can have latent demands upon the environment is that they are heterogeneous. Stabilization and sharing of the central elements of technological regimes is often not based on consensus, but on compromise.[18] Regime insiders that willy-nilly accept existing definitions of the central elements of technological regimes may be looking for opportunities to break up these definitions. Such insiders can link with outsider actors and issues to destabilize existing definitions. The existence of such insiders reflects a latent demand upon the environment that can become manifest through the actions of either regime insiders or outsiders.

A demand upon the environment can also be created as a result of earlier aggression of the existing technological regime. If outsiders succeed in delegitimating an existing technological regime, regime insiders will feel a need to win back trust and legitimacy. They can do so via rhetorical labeling and employ similar strategies to win public trust as outsiders use to erode it. If such rhetorical strategies fail, regime insiders can also begin to strive for particular changes in a technological regime to win back legitimacy and trust. We see an example of this in the *Oosterschelde* case (Chapter 6). In the first instance, Rijkswaterstaat argued that a revision of the Delta Plan was neither feasible nor desirable. When Rijkswaterstaat was not able to convince a large part of the public and was accused of not being willing to listen to the public, it became more open and prepared to consider possible alternatives to win back public trust and legitimacy. This change in policy of Rijkswaterstaat resulted in a demand upon ecologists and biologists.

Even if delegitimation of an existing technological regime does not result in regime insiders beginning to strive for changes in a technological regime, the resulting sense of crisis can offer outsider professionals an opportunity to get involved via a demand. A typical example is the nuclear reactor case (Chapter 7). Developments within and outside the technological regime of nuclear reactors created a number of problems in this regime. This offered proponents of inherently safe nuclear reactors an opportunity to get involved. They could argue that they had developed a new design approach and guiding principle that would solve the internal problems and make nuclear energy more legitimate in the eyes of the public. Their claims were not completely accepted by regime insiders, but the important point is that a situation existed in which they could make such claims and in which these claims could not be denounced immediately as ‘absurd’ by regime insiders.

In the case studies, we have found three specific ways through which outsider or marginal professionals can acquire a role in technological regimes:

1) via design criteria and their translation into more specific requirements and specifications;

2) via the development of (new) design tools like technical models and design parameters;

3) via the effectuation of new guiding principles or design approaches that allocate new roles to existing and new professional experts.

Since outsider professionals do not share the rules of a technological regime, they will have new ideas about the content, and the translations between the different elements of the triangle of technological development. Ethologists, for example, had ideas about the importance and content of animal welfare as design criterion that deviated from the existing regime and which derived from their disciplinary background (Chapter 5). Biotechnological researchers had ideas about how to design sewage treatment plants that deviated from the ideas of the traditionally involved civil sanitary engineers (Chapter 5). Ecologists and biologists as well had ideas about how to design civil engineering objects like coastal barriers and waterside bank protections that deviated from the ideas of the traditionally involved civil engineers (Chapter 6). Because of their deviant ideas, these outsider or marginal professionals were not automatically accepted as legitimate insiders by the established professionals.

One strategy that outsider professionals can employ to get accepted in a technological regime is to present themselves as objective and pragmatic experts that have relevant knowledge or design tools to offer. This strategy can be successful because outsider professionals, in contrast to most social protest groups, indeed possess cognitive resources that can be interesting for existing technological regimes. Thus, they can present themselves as scientific experts and get a hearing. Moreover, if they are prepared to be pragmatic, *i.e.* are willing (and able) to translate their knowledge into design tools or criteria that are manageable in existing technological regimes, they will be more easily accepted by regime insiders.

Being pragmatic means that outsider professionals have to give up the parts of their disciplinary baggage that will not easily be accepted in the existing technological regime. In the sewage treatment case, we saw that people with a background in microbiology could contribute to the design of sewage treatment plants by formulating design parameters that blackboxed the microbial character of the treatment process (Chapter 5). Such pragmatism may lead to tensions in the profession or discipline from which the outsider professionals come. When ethologists were pushed to formulate criteria for alternative housing systems for poultry and to contribute to animal welfare laws, this led to fundamental discussions within their discipline (Chapter 5). Some feared that pragmatism would ultimately undermine the status of ethology as a science:

> *[T]here is a danger that the combination of a growing awareness of the desirability of using behavioural studies in welfare work, and the present urgency to write new welfare laws, could result in a misuse of ethology, not intentionally, but because ethology is not yet ready to provide the answers that are being demanded of it. The very popularity of ethology could be damaging to the science ...*[19]

While a presence as pragmatic and objective experts is useful or even necessary for the first two routes, it is less so for the third. This route implies the effectuation of new guiding principles or design approaches that allocate new roles to (new) professionals. We saw this most clearly in the coastal barriers and waterside banks case studies (Chapter 6). The partial acceptance of 'integrated water management' as guiding principle created new roles for ethologists and biologists in the design of coastal barriers and waterside banks. Typically, the acceptance of integrated water management was not, and could not be, enforced by ecologists and biologists alone. Integrated water management was accepted because it became part of the mission of the existing regimes of coastal barriers and waterside banks and because it had legitimating power. As a new guiding principle, it gave the relevant regimes new legitimacy and, because of this, outsiders less opportunity to intervene in these regimes.

8.2.2 Dynamics of Sharing and Redefinition of the Elements of Technological Regimes; Technical Agenda Building

In the cases, the manifestation of aggression or demand resulted in the proposal and articulation of changes to be strived for. Sometimes, outsiders formulated concrete changes they thought should be realized in a technological regime. An example is animal welfare groups that presented scratching systems as an alternative to existing chicken husbandry systems (Chapter 5). In other cases, the outsiders were hardly interested in transforming technological regimes: airport neighbors wanted to have a societal problem (airport noise) solved and were not so much interested whether this would happen by organizational, technical or another type of measures (Chapter 7). Nevertheless, also here, social protest groups were so successful in making a secondary effect of the technological regimes of aircraft and aero-engines manifest that some regime insiders began to feel a need to strive for changes in the existing regime.

For a technological regime to transform, it is not enough that strived-for-changes are proposed and articulated. These strived-for-changes also have to become shared, so that they begin to guide the behavior of all, or at least a significant number of, actors in the regime. Here, processes of agenda building are important. Such processes of agenda building take place in arenas or fora.[20] In these arenas and fora, strived-for-changes are debated. They may be accepted, rejected or reformulated and be translated into new definitions of the central element of the technological regime.

Below, I focus on processes of technical agenda building as they take place in existing technological regimes. These processes are important for whether strived-for-changes are picked up in the existing regime, and how this happens, *i.e.* for the way in which strived-for-changes are translated into new definitions of the central elements of the technological regime.

In technological regimes, different arenas or fora focus on different elements of technological regimes. In professional fora, for example, it is the definition of technical models that is contested, while in regulatory arenas the definition of obligatory design requirements is at stake. Arenas in technological regimes are also nested, they exist at different levels. With respect to regulation, for example, we can distinguish between arenas at the local, national and international level. In the aero-engine story, we saw that regulatory arenas at the international level (the regime as a whole) were more formalized than at the other levels (Chapter 7). At the international level, the ICAO functioned as main forum for discussions about noise certification. Access to this forum was restricted to a limited number of actors who had an interest in the long-term viability of commercial flight. This clearly also affected the type of regulatory measures agreed upon: actual noise certification rules were based on conservative estimates about what was economically and technically feasible.

In technological regimes, fora and arenas as they are established in branch, professional, normalization and certification organizations are important for technical agenda building and the (re)definition of the central elements of technological regimes. The case studies show the importance of such fora as IIR, ZVEI (household refrigerators), VVVF (paints), STORA (sewage treatment plants), CUR (waterside banks), ICAO (aero-engines) and the IAEA (nuclear reactors). These fora played a major role in: the definition of CFC problem within the refrigeration regime (IIR), the choice for alternative coolants (IIR, ZVEI), the definition and development of more environmentally sound paints (VVVF), the acceptance of alternative treatment systems and a biotechnological design approach (STORA), the formulation and acceptance of alternative ways of designing banks (CUR), the formulation of noise certification measures (ICAO), the definition and the acceptability of the striving for inherent safety (IAEA).

The organizations mentioned are all ‘private interest governments,’ as this concept was defined in Chapter 2, or they are (inter)governmental bodies. As *regulators*, they are active at the global level of the technological regime (*cf.* Chapter 2). As such, they try to shape the technological regimes as a whole and undertake efforts to coordinate the activities of the various actors in technological regimes. They function as important gatekeepers for the (re)definition of such elements as technical norms and certification procedures, design approaches and technological models and the ‘acceptability’ and ‘feasibility’ of new technological artefacts in the technological regime as a whole. These organizations/fora then are important for the redefinition of the central elements of technological regimes during processes of transformation.

Actors active at the global level of the technological regime are in a position to *reflexively* aim at inside maintenance and outside maintenance.[21] Inside maintenance is directed toward keeping insiders in line and keeping technological development cumulative and coordinated. Outside maintenance aims at keeping outsiders out and feedbacks from the environment latent. In the cases, different examples of inside and outside maintenance by actors active at the global level of technological regime can be found.

One way in which inside maintenance was attempted in the cases is by closing the ranks.[22] We saw an example of this in the refrigerator story, where the German refrigerator firms, united in the ZVEI, tried to close the ranks (Chapter 4). The decision of Foron to build prototypes of a hydrocarbon refrigerator for Greenpeace was regarded as desertion. Consequently, the director of Foron was treated as an outcast in the meeting of the ZVEI.

Closing the ranks can lead to what Parkin (1974) has called 'closure as exclusion.' Actors who behave in a too deviant way will ultimately be excluded from a technological regime. We saw an example of this in the nuclear reactor story, where some critical nuclear scientists were fired (Chapter 7).

Outside maintenance is visible in arguments for the legitimacy of the existing technological regime. Regime insiders will argue that the regime is providing essential human and social goods and that external pressure on a technological regime will halt this stream of goods or diminish the productivity of the regime. Such rhetoric can also be used to keep outsiders out. Outsiders, for example environmental groups that try to get a place in technological regimes can be labeled as 'irresponsible.' It is argued that they do not represent other relevant groups in society (like users) and, thus, cannot legitimately play a role in a technological regime.

In some circumstances, inside maintenance undermines outside maintenance. In the refrigerator and the nuclear reactor story, closing the ranks was contra-productive with respect to outside maintenance because it created the impression that regime insiders had something to hide from the public or were playing a strategic game that disregarded the common good. In this way, the legitimacy of the existing technological regime was undermined.

Even when inside maintenance is not an intended outcome of the actions of the involved actors, it can undermine outside maintenance. By sticking to the existing rules of a technological regime, actors may estrange themselves - and ultimately the technological regime as a whole - from the evolving norms and values in the outside world. Ultimately, this will undermine the legitimacy of the existing technological regime. Something of this is visible in the chicken husbandry story. Poultry farmers strove for efficiency because they had become used to it and because they felt the market forced them to do so. They had no intention to achieve 'inside maintenance.' Nevertheless, by sticking to the rules of the game, they increasingly estranged themselves from the outside world.

Actors active at the global level of a technological regime can not only reflexively try to maintain the existing regime, but can also reflexively try to transform it. They may do so with an eye to the long-term viability of the interaction system in which the technological regime is embedded as a whole and in order to prevent, for example, governmental interference. According to Streeck & Schmitter, the prevention of governmental interference is an important motive for the establishment of what they call 'private interest governments', associative organizations like branch and professional organizations. They argue that:

> *This ... interest can be so strong that groups may be prepared to compromise on their substantive interests if this can save them from regulatory state interference. State agencies, on the other hand, are often prepared to accept 'voluntary' collective self-regulation as an alternative to authoritative state regulation even if this implies certain substantive concessions and a loss of (direct) control. What the state loses in this respect, it can hope to restore through lower implementation costs and higher implementation effectiveness.*[23]

This has interesting consequences for the role of associative organizations active at the global level of a technological regime. On the one hand, they have to defend the interests of their members vis-à-vis the government, and the outside world in general. On the other hand, sometimes they must disregard the (short-term) interests of some of their members, in order to remain credible as partner to the government and to gain public status.

Because of their distance to immediate and local interests, 'private interest governments' and actors active at the global level of a technological regime in general can strive for transformation of a technological regime in order to preserve or regain the long-term viability of the interaction system in which that regime is embedded. In doing so, they may disregard the short-term interest of their members, or of actors active at the local level of the regime. In a number of cases, this phenomenon is clearly discernable. The VVVF strived for a number of transformations in the regimes of paints in relation to environmental sustainability, even when this was against the short-term interests of some of its members (Chapter 4). Rijkswaterstaat and the CUR articulated integrated water management as new guiding principle and strived for its acceptance in the regime of waterside banks, even while this conflicted somewhat with the interest of local water administrators, including the *dienstkringen* of Rijkswaterstaat (Chapter 6). The ICAO agreed upon particular noise certification rules even when this was against the interest of some countries and their airlines (Chapter 7).

The cases also show how actors active at the global level, and the fora they constitute, not simply accepted the strived-for-changes proposed by others, but tried to redefine them so that they could be fitted more easily into the existing technological regime and its innovation pattern. The example that stands out here is the redefinition of 'inherent safety' by the IAEA (Chapter 7). By its advocates, inherent safety was intended as a new guiding principle for reactor design. The IAEA, however, redefined 'inherent safety' as a technical feature. Subsequently, reactors vendors incorporated this feature in so-called third generation designs. While the redefinition of 'inherent safety' by the IAEA allowed for a transformation of the regime, this was not the kind of radical departure from existing technology argued for by the inherent safety advocates.

While global level actors are clearly important, their action is not independent of local actors and the evolving interaction situation. First, actors active at the global level of the regime are compounded; they consist of a whole range of other actors with their particular interests and concerns. These compounded actors constitute fora in which processes of technical agenda building take place. The strategy of the compounded actor is the result of processes of agenda building in these fora. The resulting strategy may sometimes neglect the interest of actors that had access to these fora and took part in processes of agenda building. (Also the interests of actors that have no access to these fora may be neglected, but this is hardly amazing). Second, actions of global actors should be understood as response to the evolving interaction situation. As external pressure on a technological regime grows, the changing interaction situation may result in strategies that aim at changing the existing regime. An example can be found in the refrigerator story (Chapter 4). There, I discussed how the definition of the CFC problem within the International Institute of Refrigeration (IIR) changed as scientific evidence of ozone depletion and regulatory pressure on the regime grew. Initially, CFCs were defined as a non-problem: their ozone degrading power was not proved according to the IIR. When evidence of ozone depletion grew and governments began to consider measures against CFCs, the IIR recognized the CFC problem and defined it as the ‘avoidance of leakage of CFCs.’ When scientific evidence grew further and tighter anti-CFC measures began to be considered by governmental actors, the IIR could no longer sustain its existing definition of the CFC problem. Now, the problem became defined as requiring changes in the design of refrigerating apparatus and the type of coolants used. Ultimately, a ban of CFCs was accepted by the IIR, only the time schedules for the CFC ban were protested against. As the interaction situation changed, the willingness of the IIR to strive for a change in the refrigerator regime changed.

8.2.3 The Development and Acceptance of Technical Alternatives

The Four Innovation Patterns and Lock-ins

In the empirical chapters and in Section 8.1, I have extensively discussed how the four innovation patterns allow the development of technical alternatives that may help to transform a technological regime. I will not repeat this discussion here. Instead, I will pay attention to an aspect that received less attention in Section 8.1, namely the way in which the four innovation patterns may result in particular lock-ins.

The development of technical alternatives in technological regimes is characterized by particular lock-ins because their development and acceptance are path-dependent. In Chapter 2, we have seen how path-dependencies with respect to the adoption of a product by users can create a lock-in. During adoption, a product increasingly gains competitive advantages vis-à-vis competing products. As a result, it becomes more difficult for other products to overcome the widening gap even if these competing products would, if adopted at the same scale, perform better in the eyes of customers. Economists have analyzed such processes in terms of positive feedback.[24] However,

the phenomenon is more general: irreversibilities occur anyway and are created by prior events and actions of actors.[25]
In Chapter 4, we have seen how lock-ins can originate in the R&D policy of suppliers. In the refrigerator case, the choice for HFC 134a as alternative coolant to CFC 12 was first made by a number of chemical firms. Later, other actors like refrigerator firms, compressor manufacturers and governmental actors began to prefer HFC 134a because the chemical industry would be able and willing to supply this coolant. Inherent properties of HFC 134a played a role in this choice, but at least as important was the fact that suppliers had decided before to concentrate their R&D efforts on HFC 134a. The dominance of HFC 134a then was path-dependent. As more actors jumped the HFC 134a bandwagon, the coolant increasingly gained competitive advantage over its competitors.
HFC 134a is an example of a lock-in in a specific product. Such lock-ins may occur in any technological regime, independent of its innovation pattern. Other examples of such lock-ins, encountered in the cases, are the battery cage (Chapter 5) and the Light Water Reactor (Chapter 7). The latter is additionally interesting because many actors in the technological regime of nuclear reactors expected that the Light Water Reactor would soon be replaced by a new generation of breeders. Lock-ins thus will last longer or shorter depending on the rate of technological change that is characteristic of a technological regime. In regimes with a high rate of technological change, lock-ins in specific products will only be temporary.

The dominance of one specific product is only one form lock-ins can have in technological regimes. Another is the dominance of a specific heuristic or trajectory of technological development. In this case, technical options change over time. The difference with the first type of lock-in, however, is gradual. Most specific products, in which lock-ins occur, also change over time while the overall design remains the same. So there is a grey area between lock-ins in the sense of products remaining completely the same and lock-ins as trajectories that allow for changes in the configuration of a technology.
An example of the dominance of a specific trajectory of technological development is synthetic paints (Chapter 4). The fact that chemical suppliers usually initiate innovations in paints results in a lock-in in a trajectory of synthetic paints. Much less R&D efforts go in natural paints because such paints do not fit the R&D capacities and trajectories of the involved chemical suppliers. (Note that this lock-in is directly related to the supplier-dependent innovation pattern in the technological regime of paints.)
Which trajectories of technological development become dominant in a technological regime depends on the innovation pattern of that regime. In regimes with a supplier-dependent or R&D-dependent innovation pattern, lock-ins will relate to the R&D capacities and trajectories of suppliers respectively researchers. In regimes with a user-driven or mission-oriented innovation pattern, they will relate to functional requirements, missions or guiding principles. Typical examples of the latter are the primacy of efficiency in the design of battery cages (Chapter 5) and the primacy of safety in innovations in coastal barrier design until at least the seventies (Chapter 6).

A third type of lock-in that can be distinguished is a *technological fix*. We can speak of a technological fix if the possible solution of a problem or the fulfillment of a function is 'fixed' by a technical option.[26] Its immediate effectivity is an advantage, but there are risks because social and institutional options are lost of sight. Moreover, technical alternatives are developed with an eye to technological virtuosity, using the taking away of secondary effects or better achievement of existing functions of a technology merely as an excuse to create technological novelty.[27] Consequently, the transformation of the regime may hardly result in the removal of harmful secondary effects or the better fulfillment of (existing) functions. Moreover, especially radical new technological options will introduce their own secondary effects and unknown risks.[28]

I discussed the occurrence of technological fixes with respect to the R&D-dependent innovation pattern, but they also occur in regimes with another innovation pattern. Examples of a technological fix can be found in the *Oosterschelde* case, where a storm surge barrier was developed to overcome (political) disagreement over the relative importance of the design criteria safety and ecology (Chapter 6) and in the battery cage history, where the aviary was developed as a compromise between efficiency and animal welfare (Chapter 5).

Still, technological fixes will more often occur in regimes with an R&D-dependent innovation pattern than in other technological regimes. There, researchers have a mandate to focus on the development of new technical options without bothering too much on their possible social and economic viability and the secondary effects that such options might bring. So, a bias toward technological enthusiasm is embedded in dependencies and role-relations. This can result in technologically prestigious but economically failed innovations, like the Concorde.

The Development of Technical Alternatives in Protected Spaces

As the case studies show, development of technical alternatives does not only take place within technological regimes, but also in protected spaces outside them.[29] Examples, we encountered in the cases, are the Greenfreeze (household refrigerators), natural paints (paints), alternative housing systems (chicken husbandry systems), biotechnological water treatment installations (sewage treatment plants) and the first ecologically sound banks (waterside bank constructions). Typically in all these cases, technical alternatives were developed outside an existing technological regime because that regime was excluding the development of these particular alternatives.

The cases show different types of protected spaces in which technical alternatives are developed. One is the opportunity offered by other, but related technological regimes. We see an example of this in the sewage treatment story (Chapter 5). Alternative treatment plants were developed by biotechnological researchers from the universities with, and for, industrial clients. These installations were first developed in the related regime of industrial waste water treatment. This regime functioned as a protected space that helped to overcome the constraints inherent in the regime of sewage treatment plants and its user-driven innovation pattern. This created the opportunity to develop innovations independent from expressed functional requirements for sewage treatment plants and independent from the approval of such systems by STORA researchers.

The use of a related technological regime as a protected space is in no way unique to regimes with a user-driven innovation pattern. In fact, spinoff between different technological regimes is a common phenomenon. It may even become part of the usual innovation dynamics of a technological regime. In the regimes of aircraft and aero-engines, for example, new scientific and technological ideas and concepts - on which innovations are based - find their background not only in scientific and technological developments but also in developments in related regimes of military aircrafts (Chapter 7 and Appendix 3).

Protected spaces for the development and optimization of technical alternatives may also be created by the formation of coalitions of producers and (potential) users of technology that function independently of existing technological regimes. In the case studies we have encountered a number of such examples. One example is the development of alternative housing systems for laying hens (Chapter 5). These systems are optimized in protected spaces consisting of a coalition of (deviant) poultry farmers, researchers and producers of alternative systems and consumers. As we explained in Chapter 5, the formation of protected spaces was enabled by the user-driven innovation pattern because in this pattern market niches amount to niches for the further development and optimization of alternative technologies.

A similar example can be found in the case of waterside banks (Chapter 6). Here, local administrators of waterways together with engineering firms and building contractors developed alternative ecologically sound banks for local projects even before the striving for ecologically sound banks reached the agenda of the technological regime as a whole. Local water administrators could do so because they were relatively autonomous from the actors that formulated missions for the entire technological regime. This was a difference with the regime of coastal barriers where missions for specific projects directly derived from, or coincided with missions for the entire regime.

In the refrigerator and the paints case as well, we see coalitions of maverick actors that create protected spaces for the development of alternative technologies like the Greenfreeze and natural paints. These protected spaces are not created because little room existed to develop technological alternatives independent from functional requirements or missions. In fact, in both the R&D-dependent and the supplier-dependent innovation pattern, technical alternatives can be developed even when no clear demand for them exists. Nevertheless, also these innovation patterns are constraining for the development of particular technical alternatives. Natural paints and the Greenfreeze were developed outside the existing technological regime because they did not fit the R&D trajectories or interests of (current) suppliers.

How can technical alternatives - developed either in protected spaces or within the bounds of the existing innovation pattern - (help to) transform a technological regime? For one thing, they may function as *exemplar* for new alignments between technical configurations and functions.[30] We saw an example in the refrigerator case, where the Greenfreeze eventually functioned as an exemplar for a refrigerator with hydrocarbons as coolant.

Acceptance of alternative technologies in an existing technological regime can be achieved via the routes of user pressure and regulation. In the refrigerator case, user pressure forced the designer/producers of refrigerators to accept the Greenfreeze as feasible and desirable alternative. Subsequently, the important question was in what respect the Greenfreeze was an exemplar for new refrigerators. Was the Greenfreeze an exemplar of a refrigerator using hydrocarbons as coolant or was it an exemplar of a complete new way of designing refrigerators in which environmental groups directly impinge on the design of refrigerator apparatus? Refrigerator firms eventually were to accept the Greenfreeze as an exemplar in the first sense, but not in the second sense.

In addition to user pressure and regulation, process of technical agenda building will be important for the acceptance of technical alternatives. This is visible in cases like sewage treatment plants, where the STORA constituted an important forum for discussions about the feasibility of biotechnological treatment technologies and in the case of aero-engines, where the ICAO was an important forum for discussions about the technical and economic feasibility of anti-noise technology for aero-engines.

The particular tradeoffs and secondary effects that technical alternatives bring will be important for their acceptance by users, regulators and other regime insiders. In this respect, it is important that there is some room to further develop and improve technical alternatives before selection takes place.[31] In the R&D-dependent and the supplier-dependent innovation pattern, room to develop technical alternatives is to some extent institutionalized. Here, researchers respectively suppliers can develop and improve technical alternatives independent from direct market demand. Especially in the user-driven innovation pattern, this is more difficult. Here, protected spaces outside the existing technological regime may provide opportunities to further develop and improve alternative technologies.

Even if technical alternatives are never generally accepted in an existing technological regime, their sheer existence will influence technological development. The existence of technical alternatives may erode the legitimacy of existing technological regimes because they show that another way to fulfill particular functions exists. Moreover, technical alternatives may be used to mobilize users and regulators against technological regimes (the routes of user pressure and regulation). Regime insiders will feel forced to produce technologies that perform better or take away particular secondary effects to win - or keep winning - the competition with the alternative product.[32]

8.2.4 In Conclusion

Three phases can be distinguished in Boudon-type processes of transformation: the manifestation of feedbacks from the environment, technical agenda-building and the development and acceptance of technical alternatives. In practice, especially the second and the third phase overlap. The development of technical alternatives, proactively or in protected spaces, sometimes takes place before strived-for-changes reach the agenda of the entire regime. Technical agenda building does not usually

stop when the development of technical alternatives starts. Moreover, technical agenda building plays a role in the acceptance of technical alternatives and the way in which they, if accepted, are interpreted as exemplar for a new technological regime.
The understanding gained in the dynamics of processes of transformation is not only analytically relevant, but can also be used to make suggestions about how technological regimes can be transformed successfully. Clearly, as my cases show, no recipe for successful transformation of a technological regime exists. Still, my empirical data suggest that three things are crucial for the successful transformation of technical regimes: the manifestation of feedbacks from the environment, sharing and redefinition of the central elements through agenda building and the development and acceptance of technical alternatives.
The manifestation of feedbacks from the environment is necessary to create a certain external pressure on or internal tension in the regime so that there is room for changing the rules that make up the regime. As a result of feedbacks from the environment, certain strived-for-changes will be proposed. To achieve successful transformation of the regime, these strived-for-changes have to be translated into new definitions of the elements of the technological regime, that become shared, hence the crucial importance of technical agenda building. Finally, successful transformation is not possible without the development and acceptance of technical alternatives that embody new alignments between technical configurations and functions.

8.3 Contributions to Technology Studies

What contributions does this study make to the field of technology studies? My research design itself using explicit social science theory is interesting because the core of the field has a tradition of single case studies. I have also used case studies, for their strength in capturing the complex interactions in the development of technologies, but located them in a theoretical framework. More interesting, perhaps, than such a methodological contribution are the substantive contributions to the understanding of technology. I single out the three main contributions: 1) the mechanisms of aggression and demand; 2) the notion of innovation pattern and 3) the role of outsiders in technological development.

Aggression and Demand

A first contribution to the field of technology studies are the mechanisms of aggression and demand. This thesis suggests that these are the main mechanisms for the initiation of a Boudon-type process of transformation that may eventually transform a technological regime. It may, however, well be that the mechanisms of aggression and demand are more generally important for the transformation of technological regimes.
Looking at literature and the additional cases in Appendix 1, which I explored but did not research in detail, there are many examples confirming that aggression and demand are main mechanisms for the transformation of technological regimes.

Usually, however, these cases have been presented under different headings than aggression and demand.
An example of the initiation of a process of transformation in reaction to *aggression* is the development of the electric vehicle in response to public concern about environmental effects and subsequent regulation, especially in California (USA).[33] Although this has not yet resulted in the transformation of the automobile regime, a process of transformation was initiated in response to the aggression of the existing regime. Other examples of processes of transformation initiated due to the aggression of existing technological regimes are attempts to develop sail-assisted ship propulsion in response to the environmental impact of current ship propulsion systems[34], and attempts to introduce a safety-integrated design approach to beamer design in response to accidents with such ships.[35]
Other interesting examples can be found in the technological regime of detergents.[36] In the late fifties, early sixties, it became clear that detergents disrupted the proper functioning of sewage treatment plants and caused environmental problems for the surface waters. In reaction to this aggression, suppliers to detergents producers proactively developed new biologically degradable components for detergents. Subsequently, detergent producers substituted the original non-degradable components for the new degradable ones. A second process of transformation has taken place since the seventies when detergents came to be seen as one of the causes of the euthrophication of the surface waters. In reaction to the manifestation of this aggression, smaller companies - somewhat marginal to the existing regime - developed washing powders without phosphates. Due to their success, other producers later felt forced to switch too.
What we see here are two processes of transformation of the technological regime of detergents due to aggression of the regime becoming manifest. In the first process, only suppliers responded and developed technical alternatives proactively, which could then be substituted for the original, non-degradable components. In the second process, technical alternatives were developed in the margin, by firms which in a sense saw the public concern as an opportunity. Approaches to the design of washing powders were broken open, resulting in a transformation of the regime.
These cases emphasize a point that also plays a role in my cases. Technical alternatives are not only an element in a delegitimation detour. They can be developed consciously by (marginal) insiders to profit from the opportunity offered by a regime under pressure. In the first process, alternatives were developed by suppliers, strongly embedded in the system. In the second process, they were developed by minor players, some of which after their first successes were bought up later by big players.

In literature, many examples can be found of, successful and unsuccessful, processes of transformation initiated by a *demand* upon the environment. One example of a demand upon outsider or marginal professionals is the growing involvement of biotechnological researchers in the ‘design’ of veterinary vaccines and pesticides.[37] Another example is the demand on ergonomists to design ‘ergonomically responsible’ control rooms for, for example, chemical plants.[38] A third example is the development and introduction of the turbojet as described by Constant (1980). In this case, outsiders to the existing aero-engine community played a crucial role in initiating the turbojet revolution. These outsiders became involved via a demand; they possessed crucial knowledge for the development of the turbojet.

A further interesting example is the introduction of object-oriented design of software.[39] Object-oriented software was first developed by a number of professionals who were somewhat outside the mainstream of the existing regime. In the eighties, they succeeded in making object-oriented design an item on the agenda of the existing regime. In promoting object-oriented design, they did not only link to existing design criteria but also articulated problems in the regime to which, they claimed, object orientation would provide a solution. In other words, they made manifest a demand of the regime for better software design methods and tools.

In evolutionary economics and in industrial economics, the mechanism of demand has received ample attention, although usually under a different heading: the entry of new firms. Examples are studies of Tushman & Anderson (1986), Truffer & Dürrenberger (1997) and Stoelhorst (1997). These studies can be interpreted as describing a demand upon outsiders. Tushman & Anderson (1986) describe how periods of major technical breakthroughs in the airline, cement and microcomputer industry were characterized by the entry of new firms, either firms from other industrial sectors or newly established firms. Stoelhorst (1997) found the same with respect to the semiconductor industry: 'disruptive new technologies in the semiconductor industry were launched by firms that were relatively new to the industry.'[40] These firms have become involved via a demand.

In the technological regime of cars and that of bicycles, similar phenomena are visible. Truffer & Dürrenberger (1997) describe initiatives undertaken by respectively a Swiss watch producer and a number of new firms with respect to the development of less environmentally harmful cars. Here, we see the initiation of a process of transformation due to aggression (environmental disadvantages of current cars) and a demand on companies from outside the car industry.

In the technological regime of bicycles as well, processes of transformation have been initiated as a result of a demand upon the environment. One example is the unsuccessful introduction of the Itera bicycle, an all-plastic bicycle.[41] This bicycle was developed by a number of engineers from Volvo who later established their own company. Another example of people who became involved via a demand are the developers of the mountain bike.[42] In the words of Paul Rosen: 'Mountain bikes were 'invented' during the mid- to late 1970s. They originate in Marin County, northern California. During the early 1970s, a small group of people began to build bicycles for racing down Mount Tamalpais. These bikes, known as 'clunkers', were constructed from frames and components that happened to be lying around in people's backyards.'[43] These people also set up the first companies that commercially produced mountain bikes. Later, the existing cycle industry became interested. According to Rosen, initially especially the relatively young cycle producers, that employed post-Fordist production methods, were interested in the mountain bike.

These cases of demand suggest an additional route for the involvement of outsiders, besides the routes for the involvement of initial outsider professionals that I have discussed in this thesis. This route is the entry of new companies or existing companies from outside the regime. This route for a demand can derive from the professional knowledge that is available in these companies and not in the existing regime, but also from the fact that these companies are willing to take commercial risks that established insiders are not willing to take. This point is emphasized by Stoelhorst (1997) for the semiconductor industry: 'The semiconductor case ... shows that established firms were characterized by inertia, while new firms that were not constrained by the existing technology were able to introduce variations on it.'[44] Stoelhorst (1997) also suggests that established companies can initiate radical innovations if they use in-house cognitive resources which are not central in their strategy of technological development. This can be interpreted as a demand upon engineers within a company, in his case Intel, that are outside the existing technological regime, or at least only play a marginal role in it.

Are aggression and demand the only mechanisms that may initiate a process of transformation, potentially resulting in a transformation of the prior existing regime? On the basis of Figure 8.1 and literature, a third mechanism can be suggested. This mechanism is the diffusion of technical alternatives developed outside existing technological regimes. If such technical alternatives are adopted, they function as an exemplar for new alignments between functions and technical configurations, transforming the prior existing regime.

Clearly, technical alternatives are important, if not crucial for the transformation of technological regimes. So, development and diffusion of technical alternatives is important, but is it sufficient to transform a technological regime? An interesting example that may help to answer this question is the introduction of Very Open Asphaltic Concrete or ZOAB (Zeer open Asfaltbeton) for roads in the Netherlands.[45] This type of asphalt was developed in the United States to avoid aquaplaning at the runways of airports. At the end of the sixties, engineers of Rijkswaterstaat introduced ZOAB in the Netherlands after they had heard of it in a meeting in the USA. In the early seventies, the first tests with ZOAB were carried out. However, advantages in terms of safety, related to the reduction of aquaplaning, could not be proved unambiguously. In the eighties, ZOAB eventually became successful because another disadvantageous secondary effect of current asphalt was made manifest: noise. The manifestation of the aggression of the current regime in terms of noise, and subsequent more stringent noise regulation created room for the successful introduction of ZOAB, which has since then increasingly replaced traditional asphalt for roads.

This example shows several things. First, it underlines a general finding in the field of technology studies. Diffusion of new technologies does not take place automatically, but is an active process.[46] The case further suggests that new technical options, which can transform the rules of a technological regime, will only be accepted if there is tension within or pressure on the regime that creates room to change the rules of the regime. This tension or pressure may be latent, but must be made manifest to get a disruptive technical option accepted. This can happen via the mechanisms of demand (making manifest internal tensions or problems) or aggression (making manifest external pressure).

Studies from innovation literature confirm that aggression and/or demand are necessary to get disruptive technological options accepted and to transform a technological regime. Tushman & Anderson (1986) and Stoelhorst (1997) empirically show how several radical, disruptive, technical options were only picked up when new companies entered the market. As indicated earlier, this may be interpreted as a demand upon these companies. The ZOAB case illustrates that also aggression may be a mechanism to get a new technological option accepted.

So, studies from innovation and technology studies confirm that aggression and demand are crucial mechanisms for the transformation of technological regimes. With the help of my conceptual framework, findings often presented under different headings, can be reinterpreted and integrated into a coherent conceptual framework, which specifies a number of mechanisms and phenomena that are crucial for understanding transformation of technological regimes.

Innovation Patterns

In this study, I focused on how existing innovation patterns in technological regimes enable and constrain processes of transformation. By doing so, I gained not only insight into the dynamics of processes of transformation but also in how technical change is achieved in the absence of processes of transformation. As we have seen different actors and different mechanisms are central in bringing about technical change in the four innovation patterns. The four innovation patterns also provide outsiders different opportunities to intervene in the development of technical alternatives directly. In the R&D-dependent and the supplier-dependent innovation pattern, they can particularly do so via the creation of (diffuse) expectations that are picked up by researchers respectively suppliers to develop proactively technical alternatives. In the user-driven and mission-oriented innovation pattern they can directly impinge on the development of technical alternatives by changing functional requirements or missions. Finally, outsiders can use protected spaces outside an existing technological regimes to (let) develop technical alternatives. Such protected spaces can exist in a related technological regime, but can also be created by coalitions of (deviant) actors.

In addition to those specific insights, the notion 'innovation pattern' has an added value for technology studies. This notion was based on empirical insights from the field of innovation studies, especially on Pavitt (1984). In contrast to Pavitt, however, I did not define the innovation patterns solely in terms of characteristics of individual firms, but also in terms of *relations* among the different actors involved in technological development. In this way, the four innovation patterns were related to the notion of technological regime and the general conceptual framework of Boudon. By placing the innovation patterns into a larger conceptual framework, it became clear that they could be seen as the *structure* of a technological regime that enables and constrains the actions of individual actors and determine how these actions add up to collective effects. This means that the concept of 'innovation pattern' makes sense even if it would turn out that, on empirical grounds, the four innovation patterns as specified now are not quite adequate.

The notion that innovation patterns constitute the structure of the interaction systems in which technological regimes are embedded is especially important for the application of a multilevel approach. Following a multilevel approach, technological development is studied as the interplay between the actor level and the structural level. It helps to combine attention to the roles of actors and contingency in technological development with attention to the role of structural constraints. The latter has sometimes been neglected in technology studies, as part of their attack on technological determinism, but is important because, as Sørensen and Levold have pointed out, 'the terrain on which engineers and technological scientists move has been thoroughly shaped by previous actions.'[47] Without paying attention to the structural aspects of technological development, some aspects of technology can simply not be understood; for example, why technological regimes with different innovation patterns show different resilience against attempts of outsiders to change them.

The importance of structural aspects of technological development is now also realized by (social) constructivists who initially tended to play down the importance of structures, at least rhetorically.[48] Both SCOT (Social Construction of Technology) and actor network theory have developed concepts to come to grips with phenomena of 'normality' and the role of structures in technological development.[49] According to Bijker, any 'theory of technological development should combine the contingency of technological development with the fact that it is structurally constrained; in other words, it must combine the strategies of actors with the structures by which they are bound.'[50]

Within the field of technology studies, a multilevel approach is increasingly seen as a useful and appropriate way to handle the fundamental issue of agency versus structure. This is not only visible if one looks at such theoretical approaches as the (quasi)evolutionary approach, the technical systems approach, SCOT and actor network theory, but also in the work of historians and sociologists of technology like Constant, Hård and Blume.[51]

Thus, there is interest in, and some articulation of the levels of technological development and their interactions, even if the theoretical position of some approaches in technology, for example actor-network theory, is against the notion of levels. What is important is to get a better conceptualization of what happens at the meso-level. The structures at the meso-level can be captured by the concept of innovation pattern, constituting the structure of the interaction system in which a technological regime is embedded. My case studies and analyses have shown how the concepts 'innovation pattern' and 'technological regime' are filled empirically. It was suggested that technological regimes change more often and a shorter time-scales than innovation patterns. This creates a picture of technological change which allows economics, sociology and history to work together and provide more general understanding.

The Role of Outsiders in Technological Development

This thesis suggests that two types of actors drive the process of technical change: actors central in innovation given a particular innovation pattern (researchers, suppliers, users, governmental actors and in all cases

designer/producers) *and* outsiders. This thesis has shown that the involvement of outsiders surely makes a difference for technological development. Not in the sense that outsiders can simply enforce their visions of better technology, but in the sense that they set off processes of transformation that result in new design criteria, guiding principles, design tools and so on.
In this thesis, I selected my cases so as to represent outsider involvement in technological development. So I cannot pronounce on the overall frequency of outsider involvement, and one might wonder whether outsider involvement in technological development is (becoming) a common phenomenon or an exception (that is nevertheless interesting as a specific research site for technological development). As this thesis has made clear, and as has been emphasized by authors like Bijker[52], outsiders like societal groups can in principle always impinge on the design of particular technologies. The question is whether they actually do and whether general societal developments are taking place that make a closer and more frequent involvement of outsiders in technological development more likely. According to the sociologist Beck, a trend toward closer involvement of (initial) outsiders exists. He argues that technological (and scientific) development is increasingly becoming 'reflexive,' in the sense that not only insiders such as scientists and technologists reflect on and influence technological development but also outsiders like societal groups.[53]
In one sense, my cases suggest that outsiders will become more closely involved in technological development in the future. In more than half of my cases, adverse environmental effects were a reason for delegitimation of an existing technological regime and the initiation of a process of transformation. Typically, the environment is one of the main spheres if not *the* domain in which a certain normative disintegration between technological regimes and (other) parts of society have become clear.[54] Evidently, environmental groups and critical scientists have been successful in making manifest the environmental *un*sustainability of many current technologies and in initiating processes of transformation with respect to environmental sustainability in particular technological regimes. It might be expected that this trend will continue, especially because there are other spheres, such as 'animal welfare' and 'privacy,' in which normative disintegration between technological regimes and (evolving) societal norms and values may become clear. So, it seems likely that the role of outsiders, and in particular of societal groups, in technological development will become more rather than less important.

Notes to Chapter 8

1 *Cf.* Yin (1989).

2 The distinction between components, devices, artefacts and systems is based on Disco, Rip & Van der Meulen (1992). See also the discussion on technical hierarchy in Chapter 2.

3 *Cf.* Hughes (1983, 1987).

4 Arthur (1988 and 1996).

5 The notion of exemplar is based on Kuhn (1962). For an application to technological development, see for example Van den Belt & Rip (1987).

6 See Chapter 5 and the discussion in Section 8.2.

7 See, for example, Van den Belt & Rip (1987) and Stoelhorst (1997).

8 Clark (1985), Abernathy & Clark (1985) and Abernathy & Utterback (1978).

9 According to Snellen (1983), normative integration (congruency between the acting of an organization and societal norms and values) is one of the sources of legitimation of organizations or, in my case, technical regimes. If technological regimes produce outcomes disliked by regime outsiders, *i.e.* outcomes that are not congruent to their norms and values, there is room to delegitimize them.

10 *Cf.* Chapter 1. See also Van Lente (1993).

11 There are, of course, a number of factors that explain the different forms of regulation issued by governments in the refrigerator (CFC) and paints (VOC) case. Here, the important point is that the availability of technical alternatives, and the properties these have, partly determine the interaction situation in which governments have to act, making particular courses of action (regulation) more probable than others.

12 Beck (1992).

13 ORNL, 'The First 50 Years--Chapter 6: Responding to Social Needs,' document drawn from Internet; also appeared in *Oak Ride National Laboratory Review*, Vol. 25, No. 3 and 4.

14 Van de Poel & Disco (1996, 96).

15 Van de Poel & Disco (1996).

16 Becker (1982, 185, his emphasis).

17 Users can raise their *voice* against a harmful product or decide not to buy it any longer (*exit*). As long as there are not specific incentives to raise their voice, and if alternatives are available, most users will choose to stop buying their product instead of protesting against it (*cf.* Hirschman, 1970.)

18 *Cf.* also the discussion of sharing in Chapter 1 and Grin & Van den Graaf (1993), Hård (1993), Konda (1992) and Van de Poel (1994).

19 M.S. Dawkins, 'Battery Hens Name Their Price: Consumer Demand Theory and the Measurement of Ethological 'Needs',' *Animal Behaviour*, 31(1983), 1204.

20 *Cf.* Chapter 1. See Van Lente (1993); Albert de la Bruhèze (1992) and Strauss (1978).

21 *Cf.* Chapter 2. See Albert de la Bruhèze (1992).

22 For this mechanism, see also Albert de la Bruhèze (1992).

23 Streeck & Schmitter (1985, 19-20).

24 *Cf.* Arthur (1988 and 1996). My analysis below builds on the analysis of Arthur but goes some steps further. Arthur analyzes path-dependencies and lock-ins in cases of competition between two products. He is mainly interested in the path-dependencies and lock-ins to explain why 'inferior' technologies win the competition from products which are intrinsically better, in terms of meeting user needs, or could have been better if as much effort had gone in them as in the alternative product. In contrast to Arthur, I see path-dependencies and lock-ins as phenomena that occur in any technological regime. The rules that make up a technological regime will enable the development and acceptance of particular technical alternatives and constrain the development and acceptance of others. So, in any technological regimes, path-dependencies and lock-ins will occur.

25 Callon (1995).

26 *Cf.* Achterhuis (1995, 159-161).

27 *Cf.* Pacey (1986).

28 *Cf.* Wynne (1988).

29 For the notion of 'protected space' see, for example Van Lente (1993). The notion 'protected space' as used here is comparable, but not similar, to the notion of 'niche' used by authors like Rip and Schot (see for example Rip (1992) and Schot (1992)). They conceive niches mainly as protective against market selection, while the concept of 'protected space' is here also used in relation to other constraints inherent in technological regimes.

30 Van den Belt & Rip (1987).

31 *Cf.* Rip (1992) and Schot (1992). Protection against too harsh market selection take place in what they call niches. See also note 29.

32 This is a common effect. Old products are improved when they are threatened by new ones. See, for example, Schot (1991), Chapter 3. He criticizes the diffusion and the adoption model to understand the decline of 'old' technologies and the rise of new ones: 'I would like to conceptualize the decline of technology much more as a continuous transformation process than as a substitution of new by old technologies. A transformation in two respects: first, transformation of old and new technologies in a new pattern, and secondly, transformation of both technologies, old and new and the context in which they are deployed. The concept of co-evolution can therefore be given a new content by using it as a metaphor for both transformation processes' (*Ibid.*, 64-65).

33 Schot, Elzen & Hoogma (1994).

34 *Cf.* R. Burton, 'Fifty Years on Power from the Wind'(1983), Port of London, second edition, 46-49; J. Gerritsma, 'Windvoortstuwing voor vrachtschepen' (1981), lezing voor het symposium 'De voortstuwing van de jaren tachtig, wind zon en kolen ...,' 15 oktober 1981, Vlissingen; N. Hamada, *Trends in Technological Development for Future Ships* (Japan Marine Machine Development Association, 1984); P. Melissen, M.J. van der Flier & P.A. Kluytenaar, *Marktverkenning windvoortstuwing* (Rotterdam: Maritiem Economisch Research Centrum, 1986), Rapport; F. Smulders, *Windvoortstuwing in de kleine handelsvaart* (Nautical Innovation Services, 1985), niet officieel gepubliceerd rapport; L. Bergeson & C.K.Greenwald, 'Sail Assists Developments 1979-1985,' *Journal of Wind Engineering and Industrial Aerodynamics*, 19(1985), 45-114.

35 F. Veenstra & J. Stoop, *Beamer 2000; Safety-integrated (Re-)design; The Kindunos Method* (IJmuiden: Netherlands Institute for Fisheries Research, 1992). This may also be interpreted in terms of a demand upon safety experts.

36 De Man (1987).

37 Information from Jaap Jelsma.

38 *Cf.* E. Hollnagel, *Human Reliability Analysis; Context and Control* (London etc.: Academic Press, 1993); J.E. Rijnsdorp, *Integrated Process Control and Automation* (Amsterdam etc.: Elsevier, 1991); W.B. Rouse, *Systems Engineering Models of Human-Machine Interaction* (New York, Oxford: North Holland, 1980); Th.B. Sheridan, *Telerobotics, Automation, and Human Supervisory Control* (Cambridge (MA): MIT Press, 1992); Th.B. Sheridan & W.R. Ferrell, *Man-Machine Systems: Information, Control, and Decision Models of Human Performance* (Cambridge (MA): MIT Press, 1974); Ch.D. Wickens, *Engineering Psychology and Human Performance* (Columbus etc.: Bell & Howell Company, 1984). This case also implied a demand upon ergonomists.

39 B. Kennedy, '"The Object is the Subject"; onderzoek naar de introduktie van object-georiënteerd ontwikkelen van software' (1995), Afstudeerscriptie WWTS, UT.

40 Stoelhorst (1997, 335).

41 J. Hult, 'The Itera Plastic Bicycle,' *Social Studies of Science*, 22(1992)2, 373-386.

42 P. Rosen, 'The Social Construction of Mountain Bikes; Technology and Postmodernity in the Cycle Industry,' *Social Studies of Science*, 23(1993), 479-513.

43 *Ibid.*, 486.

44 Stoelhorst (1997, 340).

45 Based on information gathered by Fred Leffers on this subject. Main sources were spokespersons of Rijkswaterstaat and he magazines *Asfalt*, *Wegen* and *Land + Water*.

46 See, for example Disco (1990).

47 Sørensen & Levold (1992, 33).

48 See especially Latour (1987 and 1993).

49 Bijker (1993 and 1995a); Callon (1992 and 1995).

50 Bijker (1995a, 15). See also Bijker (1993).

51 See Van den Belt & Rip (1997), Bijker, Hughes & Pinch (1987), Bijker (1990, 1993 and 1995a), Bijker & Law (1992), Blume (1992), Callon (1986, 1987, 1992, 1995), Constant (1980, 1984 and 1987); Dosi (1982), Dosi *et al.* (1988), Hård (1992 and 1993), Hughes (1983 and 1987), Kemp, Schot & Hoogma (forthcoming), Latour (1987), Mayntz & Hughes (1988), Nelson & Winter (1977, 1982), Rip, Misa & Schot (1995), Rip & Kemp (1998), Schot (1991 and 1992).

52 See, for example Bijker (1992 and 1995b).

53 Beck (1992).

54 For the notion of normative (dis)integration, see note 9.

Epilogue

Moral indignation about undesirable effects of technology in society, as shown in the quote from Nader with which Chapter 1 opened, is useful but not enough. Critics like Nader have sometimes succeeded in making aggression of technological regimes manifest. This is important because it creates room to transform technological regimes in desirable directions. To achieve successful transformation, however, more is required. Technical alternatives have to be developed and new definitions of the central elements of a technological regime have to become shared. More generally, individual action or actor strategies are not enough to transform technological regimes for the better. Outcomes at the collective level, like the transformation of a technological regime, are shaped by existing regimes and patterns.

Although moral indignation is not enough, the moral or political motivation should not be forgotten either. My study and its findings do not only relate to a scholarly interest in understanding the world and its complexities, but also relate to the challenge to influence technological development for the better. More specifically, my analysis makes it possible to translate the question 'how to reduce or prevent aggression of technological regimes?' into a question about types of technological development that are more desirable than others. This is important because focusing on the first question may well, in the best traditions of rational policy making, result in the formulation of a blueprint of the future that is translated into specific measures to be implemented. As has become clear in policy analysis, the disadvantage of such a top-down route is that one almost surely ends up with proposals that are hard to implement.[1] Instead one can better start with mechanisms and processes that play a role in actual technological development and try to build on them.

This shift from goal achievement to process improvement has also been made in Constructive Technology Assessment (CTA).[2] CTA, like other forms of TA, wants to reduce 'the human costs of trial and error learning in society's handling of new technologies,' through anticipation of potential effects and feedback into design processes.[3] A favored route to do so is to include more actors into such design processes. This implies an interest in the role of what I called outsiders, and in the processes and mechanisms which occur in the transformation of technological regimes. Conversely, processes of transformation can be seen as informal CTA because they may result in the successful feedback of secondary effects to existing technological regimes and in broadening design and technological development by including outsiders.

As argued in Chapter 8, three things are crucial for the successful transformation of a technological regime. First, feedbacks from the environment have to become manifest. Second, new definitions of the central elements have to become shared and translations between them have to be made (technical agenda building). Third, new technical alternatives have to be developed and get accepted.

With respect to the first, the manifestation of feedbacks from the environment, delegitimation is an important mechanism. It is important because it helps to create room for the transformation of a technological regime. This does not mean that delegitimation or contestation is necessarily successful as a strategy to transform a technological regime, or to improve technological development. Delegitimation may lead to a trench war between opponents and proponents of a technology, with each party not listening to the other any longer.[4] As a result, transformation of a technological regime may prove impossible and interesting technical options may be overlooked.

Delegitimation and contestation are useful as a way to create room for the transformation of technological regimes, but to achieve transformation more is required: technical agenda building and the development of technical alternatives. Here, two groups of actors can provide important openings that enable transformation of technological regimes: 'regulators' or 'private interest governments' active at the global level of the regime and the innovation actors (depending on the innovation pattern). The first are, in particular, important for agenda building; the latter for the development of technical alternatives.

'Regulators' active at the global level of a technological regime have a reflexive awareness that something like a technological regime exists (even when they do not use this term). By being active at the global level, they are to some extent able to influence developments in the regime. They can use this reflexive awareness and ability to maintain the existing regime but also to transform it. Their current tendency to resist transformation may be partly overcome by following a proposal of CTA theorists: creating alignments between fora within technological regimes and fora outside them and/or establishing new fora that align technical agenda building within regimes with developments outside them.[5]

Innovation actors are important for the proactive development of technical alternatives in anticipation of future social and technological trends. Especially researchers in an R&D-dependent innovation pattern and suppliers in a supplier-dependent innovation pattern have a long-term perspective and will proactively develop technical alternatives. By developing technical alternatives, which do not fit the existing regime in all respects, they enable the transformation of that regime as shown in this thesis.

Two things seem especially important to improve the proactive development of technical alternatives in technological regimes. First, the need to have actors with the opportunity to develop long-term strategies that depart from the existing regime. Second, the avoidance of those lock-ins and technological fixes that hinder rather than further the reduction of aggression of technological regimes. (Other lock-ins and technological fixes might be quite desirable!). With respect to both, universities and government-financed research institutes are interesting loci. Both are involved in a large number of technological regimes, but in the meantime are in the position to keep some critical distance. So, they may help to develop technical alternatives that, for example, reduce aggression and/or help to overcome undesirable lock-ins. Besides, universities may play an important role in education of reflexive engineers who are aware of the complexities of technological development, inclusive the occurrence of aggression and undesirable lock-ins, and that reflect normatively about their (desirable) role in technological development.

In addition to the opportunities for the (proactive) development of technical alternatives inherent to the four innovation patterns, my cases suggest that protected spaces are important to develop alternative technologies. This shows that the strategy of 'strategic niche management,' as proposed by CTA theorists, is a useful strategy to improve processes of technological development.[6] This strategy aims at the deliberate creation of protected spaces (niches) for the development of alternative technologies. In these niches, alternative technologies can mature and eventually, during a process of transformation, be adopted in an existing technological regime that is then transformed.

Processes of transformation can be informal CTA, but they may also help to achieve more substantial goals. Processes of transformation set off either because outsider professionals or companies feel that they possess knowledge or other resources with which existing or new functions of a technology can be better achieved (demand) or because a technology has secondary effects disliked by particular groups in society (aggression). As far as processes of transformation result in the better fulfillment of existing functions or in the taking away of secondary effects, they can be said to result in better technology. If these forms are sustainable, *i.e.* if they structurally offer better possibilities for the future fulfillment of functions and avoidance of undesirable secondary effects, they result not only in better technologies but also in better forms of technological development.

The cases of coastal barriers and waterside banks show something of what such more sustainable forms of technological development may look like. In these cases, integrated water management was partly accepted as new guiding principle, broadening the range of design criteria taken into account and the range of actors involved. Because integrated water management defines ecological criteria as integral to the design of hydraulic works, ecologists and, to some extent, environmental groups acquired a role in the regime. So, the CTA goals of feedback and broadening technological development were achieved. What is more, due to the integration of ecological and biological expertise, better chances now exist to achieve the functions of waterside banks and coastal barriers, and more generally of water systems, in an optimal way. Moreover, the new emphasis on ecological design criteria and the growing role of environmental organizations make the occurrence of harmful ecological effects due to technologies designed in those regimes less likely. The changes in water management are due to the fact that a change occurred at the level of guiding principles and because of the specific content of this change. This change was not the outcome of one successful actor strategy, but resulted from intended and unintended developments in the area of water management that eventually amounted to important changes in the rules of the existing technological regimes.

For achieving more sustainable forms of technological development, individual tools and strategies are useful, but they should be evaluated against the effect they have on the rules of the game and the possibilities to change these rules in desirable directions. Such evaluations can be made by analysts and then be offered to other actors. My thesis can be applied to that end. Actors themselves can also reflect on the impact of their own actions on technological regimes. Action informed by such

reflections is not necessarily successful, because interdependencies between actors create emergent or unintended effects, but it may allow for learning how to do better in the future.
Put in this way, the issue can be seen as one of reflexive institutional change. Technological regimes, made up of rules, partake in what has been called the institutional change puzzle:

> *If institutions are stable sets of rules, then how do institutions change? Change itself undercuts the stability on which people base their expectations. Yet failure to change in the face of changing circumstances may result in institutions whose rules constrain behavior in ways that are not socially desirable (Weimar, 1995, 5).*

Weimar continues and suggests:

> *As institutional design is nothing more than purposeful institutional change, a deep understanding of design requires a conceptual solution to the puzzle of change amidst stability (Ibid.).*

I have tried to show that in addition to a conceptual solution, theoretical and empirical understanding about the dynamics of institutional change in technological regimes can be achieved. Part of this understanding relates to dynamics at the structural level, which can be modulated, but usually not at will. In this sense, the notion of institutional change must be broader than a blueprint put into action. Undertaking of institutional design then becomes understanding of change amidst stability *and* of the emergent effects of the interdependencies and role-relations between actors. This allows for reflexive social action, *i.e.* action based on insight in existing dynamics of technological and social change. Reflexivity should, however, not only be directed toward understanding technological development in order to intervene more successfully. Reflexivity should also be normative and, when useful, link up with more general philosophical discussions about what 'better' means. There is no simple answer to the question how to improve technological development. Achieving better forms of technological development requires an ongoing quest about what 'better' is and how it may be achieved.

Notes to the Epilogue

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2 Rip, Misa & Schot (1995); Schot & Rip (1996) and Schot (1996). See also Grin & Van de Graaf (1996) and Grin, Van de Graaf & Hoppe (1997) on Interactive Technology Assessment.

3 Schot & Rip (1996, 252).

4 *Cf.* Van de Poel & Disco (1996).

5 Schot & Rip (1996); Grin & van de Graaf (1996).
6 Schot & Rip (1996).

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Appendix I Exploration of Possible Case Studies

For the selection of the case studies, a number of possible cases were explored. This exploration included talks with various members of the Department Philosophy of Science & Technology (FWT) at the University of Twente. These people have done research on developments, or have practical experiences, in the fields of ship propulsion, paint technology, civil engineering, mechanical engineering, biotechnology, membrane technology, telematics, chemistry, human genetics, transport technology, car technology, clean technologies, nuclear technology, military technology, computer technology, software engineering and micro-optics. Also a draft report for the project *History of Technology in the Netherlands, 1890-1970* has been checked for possible cases. In this report nine sectors are treated: energy, water technologies, the city, transport and communications, heavy metals, agriculture, the office, mass media and chemistry. Also publications from scholars in the field of technology studies have been checked for possible cases.

Cases investigated

Technological regime	Process of transformation
Household refrigerators	The transformation toward refrigerators with environmentally sustainable coolants
Paints	The transformation toward more environmentally sustainable paints
Chicken husbandry systems	The transformation toward more ‘humane’, ‘animal benign’ chicken husbandry systems
Sewage treatment plants	The transformation toward a larger role for biotechnology in the design of sewage plants
Coastal barriers	The transformation toward the incorporation of ecological design criteria
Waterside bank constructions	The transformation toward ‘natural’ banks and the incorporation of ecological design criteria
Aero-engines	The transformation toward more ‘silent’ aero-engines
Nuclear reactors	The transformation toward ‘inherently safe’ nuclear reactors

Cases explored but not researched in detail

Technological regime	Process of transformation
Ship propulsion systems	The transformation toward sail-assisted ship propulsion
Asphalt for roads	The transformation toward Very Open Asphaltic Concrete (*Zeer Open Asfalbeton: ZOAB)*
Personal computers	The introduction of multimedia applications possibly transforming the design of PCs
Control rooms	The inclusion of ergonomic considerations in the design of control rooms
Castings	The introduction of 'scientific management'-methods in the design of castings by Hijmans in the beginning of the twentieth century in the Netherlands
Bicycles	The introduction of ATBs (All Terrain Bikes) and reclining bicycles
Veterinary vaccines	The introduction of biotechnological methods to 'design' veterinary vaccines
Pesticides	The transformation toward genetically modified bio-pesticides, especially Bt (Bacillus Thuringiensis)
Cars	The transformation toward environmentally sound cars like electric vehicles and hydrogen-fueled cars
Biological and chemical process reactors	The transformation toward biological modeling of process reactors
Beamers	The transformation toward safety-integrated design
Software	The transformation toward Object-Oriented Design of software

Appendix 2 Literature and Other Sources Used for the Case Studies

A) Household Refrigerators

This case study is based on empirical research carried out by author and Hugo Verheul, who is at the University of Delft, the Netherlands. Part of this research was financed by the SEER program of the European Community (DG XII). I would also like to thank José Andringa and Bryan Wynne for providing materials.

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B) Paints

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F) Waterside Banks

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G) Aero-Engines

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H) Nuclear Reactors

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Appendix 3 Existing Technological Regimes and Their Innovation Patterns

This appendix presents a description of several pages of the existing technological regimes and their typical innovation pattern for the eight case studies carried out. The results of this exercise are used in Chapter 3 for checking if the cases represent the innovation pattern for which they were selected.

For each of the cases the following aspects are described:

- type of innovating firm;
- type of users;
- a brief historical overview of a number of important innovations;
- the innovation pattern existing in the technological regime.

In each case, the existing technological regimes were mapped for the same countries as the studied processes of transformation. Most technological regimes were mapped for the period from the beginning of the 20th century until the moment that the studied process of transformation started. The sources used for the regime descriptions are listed in Appendix 2.

A) Household Refrigerators[1]

Country of focus: Germany
Period: 1910's-1980's

Type of Innovating Firm

Household refrigerators are designed and produced by so-called white goods manufacturers which also produce other kinds of household appliances. In 1971, 26 million household refrigerators were produced worldwide of which four million in the USA and 12 million in Europe.[2]
The world largest manufacturer of refrigerators is Whirlpool; the market leader in Europe is Electrolux.[3] Other large refrigerator manufacturers include Bosch-Siemens, Mitsubishi, Matsushita, Hitachi and General Electric. Most of these firms are multinationals with production facilities in different countries, producing different brands of household refrigerators. German refrigerator manufacturers include Bosch-Siemens, Liebherr, Miele,[4] Bauknecht (Whirlpool), AEG,[5] and DKK Scharfenstein (East Germany). Bosch-Siemens is market-leader in Germany. Refrigerators are now manufactured in highly specialized automatized assembly lines.[6] Low-cost production and product differentiation (by added features to more or less standardized models) are main company strategies.[7] Product innovation seldom takes place or changes the product only marginally. The producers of household refrigerators are scale-intensive firms. Emphasis is on process innovation and economies of scale.

Type of User

Users of household refrigerators are anonymous consumers; they are not known to the refrigerator manufacturers. Refrigerators are mass-produced. The household refrigerator is a device that now can be found in almost every Western household. In Europe, the household refrigerator quickly spread after the second World War. In countries like Germany and France, the percentage of households having a refrigerator rose from less than 10% in 1950 to more than 90% in 1975.[8]

Innovations; Historically

Most of today's household refrigerators are so-called compression machines. The general configuration of these machines and the kinds of (sub)devices employed are largely the result of choices made earlier this century. Since then, innovation has been incremental.

The first household refrigerators were developed in the beginning of the twentieth century. They were based on refrigeration technology developed in the nineteenth century for such purposes as ice making, brewing and transport of meat.[9] A number of refrigerating machines had been developed and refined in the nineteenth century. For the history of the household refrigeration the most important among them were the compression and absorption machine.[10] The major difference between both machines is the type of cooling cycle employed.[11]

In 1918, the first commercially produced household refrigerator was sold in the USA.[12] It was produced by Kelvinator and was a compression machine. By the early twenties, some tens of companies were active in the field of household refrigeration in the USA. Most of them concentrated on the compression machine. Only some of these companies were so well financed that they could afford the large sums of money, which were needed for further development work on household refrigerators. While important innovations in the design of compression refrigerators materialized in the USA, an important innovation in absorption technology took place in Sweden.[13] Around 1920, two young engineer students, Munters and Von Platen, succeeded in designing a continuously running absorption machine that could be used at home. The Swedish firm Electrolux and the American firm Servel further exploited the design. In the mid twenties, the first absorption machines came on the market. Industrial production started in 1931, both in Sweden and the USA.

In the late twenties and early thirties, absorption machines were technically at least at equal footing with compression machines, according to technical experts.[14] Nevertheless, compression machines became the dominant design in the USA. A main reason was that substantial companies like General Electric (selling its first household refrigerator in 1925), Westinghouse (entering the market in 1930), Kelvinator and Frigidaire (founded in 1916 and purchased by General Motors in 1919) all concentrated on the compression machine and were not interested in absorption machines.[15] Therefore, especially in the USA, much more effort was put in the development and marketing of compression machines. As a result, compression machines quickly dominated the US market for household refrigeration. In Europe, the absorption machine would dominate for quite some time, with Electrolux as main producer.[16] In 1962, still half of the household refrigerators produced in Great Britain, Switzerland, Denmark & Sweden were absorption machines.[17] Later, also in Europe the compression machine became the dominant design.[18]

Most of the early household compression refrigerators used sulfur dioxide (SO_2) as coolant. Also, hydrocarbons were sometimes used.[19] In 1930, chemists at General Motors developed the CFCs, which appeared to be excellent coolants. Apart from having good thermodynamic properties, CFCs were nontoxic and nonflammable, in contrast to the toxic sulfur dioxide and the flammable hydrocarbons. General Motors and Du Pont in a brief period reached an agreement for the development, production and use of CFCs.[20] This eased the introduction of CFCs as coolants. By the late forties, CFCs had become the dominant coolant for household refrigerators.[21]

Two important technical developments that took shape between 1950 and 1975 were the universal use of the hermetic compressor and the use of (thinner) insulation of lower thermal conductivity.[22]
The hermetic compressor was first used by General Electric in the twenties. In 1946, large scale production started. In time, the hermetic compressor became more efficient, reliable and silent. Smaller and smaller compressors could be used to reach the same refrigeration capacity and consequently less coolant was needed. According to some estimates, the required coolant for a household refrigerator fell from 1.5 kilograms in the thirties to thirty to fifty grams in the nineties.[23]
With respect to the insulation, polyuererethane foam, blown with CFC 11, became commonly used. Due to its lower thermal conductivity, this foam allowed the use of thinner insulation.

Innovation Pattern

Important innovations in household refrigerator design related to component parts or devices, like the coolant and the compressor. However, these innovations were not clearly supplier-dependent. CFCs, for example, were invented by engineers working at General Motors, a producer of household refrigerators. Nevertheless, as far as other actors than refrigerator firms are involved in innovations, it were suppliers. Below, I will argue that more radical innovation, which rarely take place in refrigerator design today, will usually be supplier-dependent. First, I describe the characteristics of the suppliers of refrigerator firms.

The major suppliers of refrigeration producers are chemical concerns and suppliers of special devices like compressors, condensers and evaporators.
The chemical industry supplies coolants, lubricants, isolation materials and plastic for the inner mantle of the refrigerator to the refrigerating manufacturers. Most of these chemical concerns are (very) large and operate on world scale. Major CFC producers are Du Pont, Allied-Signal, ICI, Bayer and Hoechst. In the eighties, Du Pont was the world's largest producer of CFCs. In 1988, Du Pont produced 25% of the world's CFCs.[24] In 1987, its Freon Product Division, responsible for the production of CFCs, had eleven CFC factories over the world employing 1200 people. Nevertheless, the sales of CFC amounted to only 2% of the incomes of Du Pont. Like most chemical firms, Du Pont has relatively much CFC R&D capacity

since it is large and supplies those chemicals not only to the (household) refrigerating manufacturers but to several other branches of industry as well. Specialized suppliers supply refrigerator parts like compressors, condensers and evaporators to the refrigerator manufacturers. Most of these suppliers are large and operate at world-scale. The worldwide supply of compressors is controlled by a small number of companies including Mitsubishi, Matsushita, Sharp and Sanyo in Japan and Danfoss, Neccis, Aspera (Whirlpool), Zanuzzi and Unidad Hermetica (Electrolux) in Europe.[25] Danfoss is the critical supplier for a large number of European refrigerator manufacturers. As the list already shows, a number of compressor manufacturers are owned by large refrigerator firms (Whirlpool, Electrolux, General Electric, Mitsubishi, Matsushita).

The customer-supplier relations between refrigerator firms and their suppliers have consequences for the extent to which refrigerator firms can innovate independently from their suppliers. Features of household refrigerators that are independently decided by the refrigerator manufacturers include the major dimensions of the refrigerator, the number of doors (one, two, three), the number of compressors, the place of the evaporator and the thickness of the insulation layer.[26] In other words, the refrigerator manufacturers independently decide about the configuration of the refrigerator, given a number of existing parts supplied by specialized suppliers.
To meet requirements like energy efficiency, reliability and durability, it is very important that the different parts of the refrigerator are closely tuned to each other.[27] Therefore, more radical technical innovations in household refrigerator design require close cooperation between household refrigerator firms and their suppliers.[28] This does not necessarily mean that refrigerator manufacturers are completely dependent on their suppliers for more radical innovations. While, refrigerator manufacturers are dependent on what their suppliers can and are willing to supply, suppliers are also dependent on what refrigerator firms are willing to use. Sometimes, competition among suppliers may force them to deliver what the refrigerator firms want.[29]
Here, making a distinction between the two mentioned groups of suppliers is useful. Firms producing compressors and the like are specialized suppliers, who are in a relation of mutual dependency with refrigerator firms. Chemical firms, on the other hand, are science-based firms. They do relatively more R&D than refrigerator firms. Only a very small part of the income of these chemical concerns is dependent on the supplies to refrigerator manufacturers. So, it seems that refrigerator firms are more dependent on what chemical concerns are willing and able to supply than chemical concerns are dependent on what refrigerators manufacturers are willing to use. Therefore, one might expect that more radical innovations implying a change in coolant would be dependent on chemical firms.

B) Paints[30]

Country of focus: the Netherlands
Period: 1900-1980's

Type of Innovating Firm

Until about 1800, most paints were formulated by painters, who bought the required raw materials like pigments, terpentine and linseed oils from mills or traders.[31] In the nineteenth century, an increasing number of Dutch companies started the production of ready-to-use paints.[32] By 1900, the Dutch paint industry consisted of more than ninety companies, which employed 1,300 people.[33]

In the Netherlands, there are nowadays about ninety companies, which produce paints.[34] Most of these companies are (very) small. Their average size is 67 people.[35] About two thirds of the paint companies employ fewer than 50 people.[36] The existence of many small companies that produce paints is not typical for the Netherlands.[37] In Western Europe, about 1,300 companies are members of the European branch organization CEPE.[38] These companies employ about 100,000 people. The average company size in Europe is 46 people. In 1988, two thirds of the paint companies had fewer than 50 employees.[39]

Most small paint companies produce specialized, often tailor-made, paints for industrial applications. For these firms, suppliers are often an indispensable source of innovation, because of the raw materials they deliver and which determine the performance of paints to an important degree. The small paint producers can, therefore, be characterized as supplier-dominated firms. They also have some characteristics of specialized suppliers, given their often close relation with (industrial) users, who may also be involved in product innovation.

Besides the large number of small paint companies, there are several medium-sized and two large paint manufacturers in the Netherlands. The two large paint manufacturers, Sigma and Akzo Coatings, dominate the market, especially in the do-it-yourself and the building & construction sector. In 1990, Sigma and Akzo Coatings accounted for approximately 60% of the domestic paint sales in the Netherlands.[40] Both companies operate worldwide and are part of larger chemical concerns: Sigma of Petrofina, Akzo Coatings of Akzo.[41] These large paint firms are characterized by some vertical integration and, given the amount of R&D they do, have some characteristics of science-based firms. Nevertheless, also these large paint manufacturers do not produce all raw materials, they use, themselves. Therefore, they stay dependent on their suppliers for at least some innovations.

Type of User

Paints are used by both anonymous consumers and professional users. In fact, many different paints exist for different applications. Market segments that are usually distinguished in the Netherlands are the do-it-yourself sector, the construction and building sector, industry and marine applications. These different market segments are characterized by different relations between paint manufacturers and customers.

In the do-it-yourself (DIY) sector, consumers are anonymous to the paint manufacturer. Paint is mostly distributed through the retail trade and (DIY) super markets. There are several collaborations in distribution that are closely linked to either Akzo or Sigma Coatings. Sigma and Akzo dominate this market segment, each offering several brands.
In the construction and building sector, paints are applied by professional painters. About 5,000 painting companies are active in the painting business and employ about 30,000 people.[42] Most companies are very small. Two branch organizations are active in the painting business. All companies are obliged to be members of the *Bedrijfschap voor het Schildersbedrijf* (Trading Organization for the Painting Business). Cooperation between paint manufacturers and the painting business also takes place in the *Stichting VerfToepasing* (SVT, Foundation for Paint Application) which was established in 1956. Sigma and Akzo play an important role in the construction and building sector although they are not as dominant as in the DIY sector. More than in the DIY market, product information and advice are important. Some paint manufacturers offer courses in paint application for professional painters.
The industrial (and marine) sector is very diverse. It includes a large range of products like furniture, coils, consumption articles and car (re)finishes. Many products are tailor-made. Some niche markets are national, others are international. In the market for car paints, for example, many multinational paint companies are active. Paints for wooden furniture, on the other hand, are mainly produced by small local paint manufacturers.

Innovation; Historically[43]

The performance of paints by and large depends on the raw materials (component parts) used. Therefore, innovations in paints usually followed on innovations in raw materials. (For an overview of the raw materials used in paints, see Chapter 4).
Important innovations in the manufacture of paints in the nineteenth century were the use of stand oil and the introduction of so-called Japan lacquers.[44] Stand oil is linseed oil heated for some time. The use of this oil improved the quality of the paint. Japan lacquer was introduced at the end of the nineteenth century in the Netherlands. It consisted of a mixture of pigments, linseed oil, stand oil and natural resins. The use of natural resins reinforced the coating film. While the use of natural resins was not new, Japan lacquer was the first covering, glossy lacquer to be produced on a more or less industrial scale.
In the twentieth century, a large number of new, synthetic, raw materials were developed for paint manufacture by the science-based chemical industry, especially in the USA and Germany. I highlight some of the main developments.
In the field of pigments, an important development was the introduction, around 1918, of the synthetic white pigment titanium dioxide.[45] Advantages of this pigment were its extreme whiteness, its good covering power, its chemical inertness and its virtual nontoxicity. Despite its high costs - which initially led to many objections against this pigment - by the Second World War it had become the dominant white pigment.

In the field of binding agents, an important development was the introduction of nitrocellulose lacquer.[46] The use of nitrocellulose as binding agent was already known in the nineteenth century, but nitrocellulose lacquer was hardly used until it became popular in the USA in the 1920's for such applications as cars and later furniture, leather and paper.[47]
Nitrocellulose is one of the new binding agents that became used in the twentieth century. The twenties and thirties of this century witnessed the development of many synthetic resins, some of which proved to be excellent binding agents. The most important among these resins were the alkyds, a type of polyesters. By 1928, oil modified alkyds came in use in the USA. This offered paint manufacturers the opportunity to formulate paints with good drying performance, excellent color characteristics and good durability. In the Netherlands alkyd-based paints were introduced in the mid thirties.[48] After the Second World War, alkyds became the dominant type of binding agent. They are used in for example lacquers, primers, masonry paint and various kinds of industrial coatings.
In the field of solvents, the traditional terpentine was replaced by synthetic solvents. Such volatile organic compounds (VOCs) like white spirit have since become commonly used. Water can also be used as ‘solvent’ or medium. Since many resins like alkyd do not dissolve in water, water-based paints are usually emulsion paints. In the twentieth century, a number of such paints have been developed. Best known are the latex paints, which were developed after the Second World War and are often used as masonry paints.[49]

Important developments in application techniques also took place in the twentieth century.[50] Traditionally paint had been applied by brush, which is, with the roller, still the common technique at home and in the building industry. Especially for industrial use of paint, however, several other application techniques have been developed. The spray-gun was introduced in 1907 and it was much used to paint cars with nitrocellulose lacquer in the twenties. A great advantage of the spray-gun was its speed. Moreover, the technique was specially apt for the application of nitrocellulose lacquers, which due to the high volatility of the solvents used were not ideal to apply by brush.
Other application techniques followed the spray gun. They included the dip tank, flow-coating and electrostatic spraying. In the latter method, very small paint particles are electrically charged and directed towards the article to be painted that is at earth potential and thus attracts the paint particles. An important advantage of this method is that less paint is spilled than by traditional spraying techniques.

Especially after the Second World War, many of the innovations mentioned above were adopted in the Netherlands. Moreover, many new additives for paints came onto the market in the fifties and sixties. In the early seventies the developments in raw materials began to slow somewhat. This is not to say that developments in raw materials stopped; they became less ‘revolutionary’ than before.

Innovation Pattern

Many innovations in paint started with the development of new raw materials (component parts). Most of the raw materials used for the formulation of paints are supplied by the chemical industry. Binding agents (and additives) are provided by chemical firms like BASF, Bayer, ICI and Akzo. Solvents (VOCs) are supplied by petrochemical concerns like Shell, BP and Esso. Pigments are often produced by specialized firms. Pigments used in the Dutch paint industry are mainly supplied by German firms.[51]

Of the raw materials used (binding agents, solvents, pigments and additives), especially the binding agents, and to a lesser extent the additives, are important for the performance of paints. The chemical firms that supply these materials also do (fundamental) research on the properties of these materials. Many of these firms (Akzo, Sigma, Bayer, ICI) are also active in the production of paints, but even these firms do not produce all the binding agents they use themselves.[52] So, innovation is usually supplier-dependent.

Innovations are not only supplier-dependent because the chemical suppliers of binding agents deliver the necessary raw materials, but also because they provide information on the properties of binding agents, deliver guidelines for recipes and carry out (fundamental) research. So, the suppliers possess crucial knowledge for paint design and production. This is not mean that paint manufacturers do no carry out research. In fact, since the sixties, a serious number of (polymer) chemists have found employment in paint manufacture.[53] Nevertheless, the formulation of paints still very much is a matter of 'trial and error,' and of 'mixing cleverly.' Experience with existing paint recipes, empirical research into the relation between performance characteristics of paints and their composition and (standardized) tests are the main ways to gather knowledge for paint design.[54]

At least until recently, little fundamental insight in the performance of paints in relation to their composition existed. Of course, there was some basic understanding of the interactions between the different components, but not to the extent that the performance of paints could well be predicted on the basis of their composition, or that a required performance could be directly translated into a particular composition. The results of (standard) tests could often not be related to the composition of paints, or to molecular properties or interactions.[55] Most of the research done investigated empirically the relation between paint composition and performance.[56] So, research on paints did take place, both in companies and in research institutes, but it was supportive rather than innovative.

C) Chicken Husbandry Systems

Country of focus: the Netherlands.
Period: 1930's-1970's

Type of Innovating Firm

Until the fifties, sixties, housing systems (sheds) for laying hens were often built by the farmers themselves or by building contractors. Often, the design of these husbandry systems was based on drawings issued by governmental counseling services and farmers' organizations.[57] With the battery cage, designing became a specialized activity carried out by specialist firms.[58]

Today, chicken husbandry systems like battery cages are produced by a limited number of Dutch firms like LACO bv, Rijvers bv and Farmtech.[59] Besides, foreign firms sell laying baying batteries at the Dutch market. Most of the battery cage producing firms also produce other kinds of mechanical devices for poultry sheds like feeding systems and manure removal systems. Producers of chicken husbandry systems are usually small. They can be characterized as *specialized suppliers*.

Type of User

Chicken husbandry systems are used by poultry farmers. Laying hens are now usually kept in battery cages at large specialized poultry farms. Due to the developments in poultry keeping, which I will describe in some detail below, poultry farmers have become entrepreneurs borrowing capital from the bank, buying laying hens from breeding farms, pharmaceutics against animal diseases from the pharmaceutical industry, feedstuffs from animal feed firms and battery cages and other mechanical devices from specialized firms. Poultry farms are professional users of battery cages.

Battery cages have a life time of roughly fifteen years.[60] For poultry farmers, it is crucial to sell eggs for a price that at least compensates for the costs. This usually means that they try to produce as cheap as possible. Efficiency is, therefore, an important criterion in chicken husbandry design.

Innovations; Historically[61]

Traditionally, chickens were held outside on the farm yard. In the thirties, Dutch farmers began to build special houses for chickens and to keep them indoors for several months during the year. In the fifties, chickens became to be kept in big sheds in the fifties and in the early sixties slatted floors were introduced in such sheds. This made it possible to keep more chickens per square meter. Later in the sixties the battery cage became increasingly popular. This system made it possible to keep even more chickens per square meter and to produce eggs in a more efficient way than the existing systems. Because of the importance of the battery cage for today's technological regime of chicken husbandry systems, I will discuss its history in some detail.

In 1911, Professor J. Hulpin of the University of Wisconsin built what were probably the first cages in which to house chickens for egg production.[62] The first serious experiments with what later became known as 'battery cages' or 'hen batteries' were carried out in the USA in 1924 at the Ohio Agricultural Experiment Station.[63] Starting in the thirties, battery cages were commercially produced in the USA and the UK, but at that time the system was not yet in widespread use.[64] Most authors locate the large-scale introduction of the battery cage for egg-production in California in the fifties.[65] The increasing popularity of the battery cage at that time and place seems to be directly related to the emergence of large-scale poultry farms. The battery cage made it possible to keep a very large number of chickens on a small area in an efficient way.

Large-scale poultry farming would have been impossible without scientific insights into the nutritional and health requirements of chickens.[66] So, the existence of scientific disciplines like veterinary science and animal husbandry was a precondition for the use of the battery cage on a large scale. Moreover, this essential knowledge had to be made available to farmers in a practical way.
In fact, a cognitive infrastructure around the husbandry of laying hens had already emerged long before the development of the battery system. By 1850 the first poultry organizations had been established in the United States.[67] By 1870 the first specialized magazines on poultry farming had appeared. Between 1870 and 1900, more than 200 different poultry magazines were founded.[68] Although a great number of these folded before 1900, by then an institutional infrastructure had been established to exchange information on and experience with poultry husbandry. This included the exchange and distribution of scientific findings. In 1921 the first international congress on poultry farming was held.[69] In the same year the International Association of Poultry Instructors and Investigators was established; changing its name in 1928 to World's Poultry Science Organisation. Various scientific journals on poultry and poultry husbandry were established.

The battery cage was not widely used in the Netherlands until the sixties, although there was a lot of publicity about battery cages in the thirties and fifties. Two reasons can be given for this late adoption. In the first place, there was a lack of specialization in Dutch farming. Until the fifties, most farms in the Netherlands were mixed. As long as keeping chickens for egg production was only one of the activities of the farmer and therefore of marginal importance for his or her income, there was little reason to invest heavily in battery cages to produce eggs more efficiently. The second reason was the absence of farms, whether mixed or specialized, where poultry was held on a large scale. The absence of this kind of farms was mainly due to governmental regulations. During the Second Word War, animal feed had been lacking and a system of governmental allocation of poultry feeds and chicks had been introduced. After the war, it was decided to continue this system, which was especially advantageous for smaller farms. Eventually, the system was abandoned in 1952. Farmers could now keep as much poultry as they wanted. Almost immediately, the animal feed suppliers began to plead for the introduction of the battery cage system. However, in 1953 the so-called *Pluimveeregeling* (Poultry Regulations) was issued putting again a legal ceiling on the number of chickens a farmer was allowed to keep. This *Pluimveeregeling* was initiated and supported by the farmers' organizations, because they feared the emergence of a poultry industry in the hands of outsiders. While a number of exceptions to the *Pluimveeregeling* were allowed by the government, the resulting small scale of the sector did not provide an incentive to invest in more efficient housing systems like battery cages.
In 1961, the *Pluimveeregeling* was revoked, followed by rapid upscaling of the sector. The proportion of hens kept at farms with more than 1000 chickens rose from 7% in 1961 to 23% in 1964 and 40% in 1966.[70] The number of farms where poultry was kept fell from about 199,000 in 1960 to about 94,000 in 1967.[71] Meanwhile, the number of specialized poultry farms increased.

The decline in the number of farms and the rise in number of chickens kept per farm was not only due to the revocation of the *Pluimveeregeling* but also to developments in the market for eggs. In the fifties, the Netherlands became one of the most important egg exporters in the world. The establishment of the European Economic Community (EEC) in 1958 seemed to offer good opportunities for a consolidation or expansion of this position, because the EEC open market would put an end to the protectionist measures of some (EEC-)countries like England. However, the formation of an open market was prefaced by a transition period of six years. During this period, EEC-taxes were imposed, disadvantaging countries like the Netherlands that had achieved a high productivity per hen. Occasionally, these EEC-taxes were even higher than the existing import taxes. The result was a decline in Dutch egg exports from 3.4 billion in 1961 to 1.3 billion in 1966.[72] During this period, many existing farms disappeared. Especially the large farms producing eggs efficiently were able to survive.

In the sixties, and partly as a result of these developments, Dutch poultry farmers began to demand housing systems that could accommodate more hens per square meter and ultimately produce eggs more efficiently. Keeping chickens indoors had in any case already become common practice in the Netherlands by that time. Normally this was done in big sheds, in which large numbers of chickens were kept on the floor. Early in the sixties slatted floors were introduced in such sheds and the traditional manure area was covered with slats and enlarged to half and later two thirds of the entire floor area.

In the latter half of the sixties the battery cage became increasingly popular and the system progressively replaced the traditional housing systems and the slatted floor system. Although the housing costs per chicken in laying batteries were probably somewhat higher than in other systems, the battery cage had a number of advantages over slatted floors (and traditional housing systems); advantages like lower food conversion, a smaller likelihood of diseases (due to the absence of litter in battery cages) and better egg quality.[73] Moreover the system required less labor per hen and in particular did not require the collection of so-called ground-eggs - *i.e.* eggs laid on the ground by hens.[74] In the sixties and early seventies there seemed to have been some discussion about the efficiency and advantages of the battery cage vis-à-vis slatted floors. Despite these discussions, the battery cage rapidly became popular. In 1971, 50% of the chickens were housed in battery cages; in 1976 this had risen to 80%. Presently more than 90% of the chickens are housed in hen batteries.[75] An important reason for the rapid adoption of the battery cage in the sixties was probably also the fact that after 1965 - when the transitional EEC-taxes ended - the profitability of poultry farming started rising again. In these circumstances it was especially advantageous for farms with a large number of hens to switch to battery cages.

Innovation Pattern

With the introduction of the battery cage, the design of chicken husbandry systems moved out of the hands of farmers and into the hands of engineers and technicians employed by specialized firms.[76] While poultry farmers are usually no longer directly involved in the design of chicken husbandry systems, the innovation

pattern of the technical regime remained user-driven. Functional requirements of users continued to play an important role in battery cage design and innovation Although the battery cage was ‘invented’ by researchers at an American university, it merely seems to have derived from practical considerations. The further development of the battery cage was accompanied by a lot of trial and error and testing, in experimental setups as well as in more realistic circumstances. Feedback from users, *i.e.* the poultry farmers, played an important role. At present, after several decades of development, the search for more efficient systems has become a matter of detail design.[77] Design adaptions often seem to follow on functional requirements expressed by users.
Such design adaptions are accomplished at research institutes and at the firms producing battery cages. With respect to research an important role is played by what is nowadays called the ‘Spelderholt Center for Poultry Research and Extension’ and which was established in the 1920's.[78] Practical research was long carried out at special experimental stations (farms), but since 1990 it has been concentrated at the *Spelderholt*. Research at the *Spelderholt* is paid by the government and the poultry farmers. Usually it is practice-oriented and guided by the functional requirements of poultry farmers.
Detail design of battery cages is accomplished in the firms producing battery cages.[79] In most of these firms, designs are to an important extent based on experience: one knows what will work and what won’t.[80] Structured models are used only in a scanty measure in the design of chicken husbandry systems because it is hard to foretell with a model how chicken will behave in a new kind of husbandry system. Therefore, new housing systems (battery cages as well as alternative systems) have to be tested in practice. Some firms have established special test farms for this goal; others sell a small number of prototypes and improve the system on the basis of the experience gathered. For the evaluation of test results, parameters such as food conversion, weight per egg, number of eggs per hen, drop out rate and emission of ammoniac exist. The ‘required’ value of these parameters is dependent on the chicken breed.

Due to the above sketched developments in the market for eggs, efficiency has become a guiding principle in battery cage design, research and use. This guiding principle is described in more detail in Chapter 5. Here the important point is that is immediately is related to the functional requirements of poultry farmers who want to produce eggs in an efficient way. So, the innovation pattern in today’s technological regime of chicken husbandry systems can be characterized as user-driven.

D) Sewage Treatment Plants

Country of focus: the Netherlands
Period: 1900-1970's

Type of Innovating Firm

Until the sixties, an important role in the design of sewage treatment plants in the Netherlands was played by the Netherlands Institute for the Purification of Waste Water or RIZA (*Rijksinstituut voor de Zuivering van Afvalwater*), which was established in 1920.[81] The RIZA formulated requirements for sewage treatment plants, chose a treatment technique and determined the value of the main parameters of the plant. The civil engineering and electrical-mechanical part of the treatment plant were usually designed by independent consulting engineers, who often built the installation too. (Today, installations are usually built by independent building contractors).

Since the fifties, the role of the RIZA in designing sewage treatment plants has been taken over by engineering firms like DHV, TAUW, Witteveen + Bos, Haskoning, Tebodin and Grontmij.[82] These firms usually already designed the mechanical and electrotechnical part of sewage treatment plants.

Most engineering firms are also active in other civil engineering areas like building construction, road construction, water management and the design of sluices and barriers. In 1984, about 50% of the activities of engineering firms were devoted to waste water treatment. In that year, a thousand employees of these firms were active in waste water treatment.[83]

Engineering firms can be characterized as specialized suppliers. In the design process, they work closely together with their principals.[84] In the case of sewage treatment plants, these are usually Water Boards (see below).

Type of User

Until the Second World War, sewage treatment was usually a municipal responsibility.[85] After the Second World War, sewage treatment increasingly became the responsibility of so-called Water Boards, a special type of local authorities.[86]
Water Boards are so-called functional or goal-oriented types of administration.[87] This means that they have been established for one or more circumscribed functions, while, for example, municipal authorities can in principle govern ‘all’ activities at their territory. Water Boards have a long history; the first Dutch Water Board was established in about 1122. Water Boards mostly have a local or regional character. Throughout history attempts have been undertaken to centralize them, mostly however with little success. Only in the last century the number of Water Boards has seriously declined. Historically, the functions of Water Boards have varied from board to board and the various historical epithets, under which they are known, often refer to these various functions. Functions of Water Boards have included drainage, water management, the buildings of dams, dikes, sluices, bridges and the maintenance of shipping routes.

At the end of the forties, *de Dommel* was the first Water Board to become responsible for sewage treatment.[88] It was followed by the Water Boards *Geleen en*

Molenbeek (1950), *de Aa* (1952) and *Regge en Dinkel* (1962). In 1970, sewage treatment officially became a provincial authority. Provinces, however, could delegate this task to other authorities as several of them did.[89] As a result, sewage treatment is now the responsibility of either Provinces, specially established Treatment Boards or 'traditional' Water Boards.

While most municipalities, except for some larger cities like Amsterdam[90] had not employed 'sewage treatment specialists,' most Water and Treatment Boards set up technological divisions and laboratories when they became responsible for sewage purification. These technological divisions and laboratories enabled them to analyze samples of waste water, to formulate requirements, to choose treatment techniques, etcetera. So, Water Boards are sometimes actively involved in the design of sewage treatment plants.

Water Boards can be characterized as the 'government as clients.' They have an elected administration. Traditionally, Water Boards were almost autonomous in their policy. Since the Dutch Pollution of Surface Waters Act or WVO (*Wet Verontreiniging Oppervlaktewateren*) became effective in 1970, this situation has changed somewhat.[91] Since then, abatement of water pollution and the formulation of effluent standards are increasingly organized at a national level. Until 1989, national five-year plans, so-called IMP's (*Indicatieve Meerjarenprogramma's*), were formulated to combat water pollution. In 1989, the abatement of water pollution was integrated with other aspects of water management, resulting in the Third Memorandum on the Water Economy (*Derde Nota Waterhuishouding)*.[92] Water Boards have to comply with this memorandum.

Innovations; Historically

The development of early treatment technology is related to the introduction of sewers in the nineteenth and twentieth century.[93] These released problems like stench and diseases in the cities, but also sometimes caused severe water pollution in rivers. Rivers not only began to stink but also became carriers of diseases.[94] At the end of the nineteenth century, sewage farms were established in England as a kind of solution. At these firms, the fields were irrigated with sewer effluents. Later, the Englishman Frankland developed a more efficient variant to this method: intermittent soil filtration. Still later other methods were developed like contact filters, trickling filters and the activated sludge process. English researchers played an important role in these innovations, as did the American Lawrence Experimental Station of the Massachusetts Health Department.

In Germany and the USA, major advances were made in the development of anaerobic or 'sedimentation' tanks. Chemical methods for the purification of sewage were also developed. Around 1900, for example, the so-called Kohlenbreiverfahren using grinned brown coal and iron sulphate to treat sewage, captured much attention.

In the Netherlands, sewage treatment plants came to be built on a small scale at the beginning of the twentieth century.[95] Knowledge about these, usually foreign, treatment technologies was gathered by study trips, foreign literature and from articles that appeared in *De Ingenieur*.[96] Until the Second World War, few treatment plants were actually built in the Netherlands. The variety in methods was nevertheless large, including various ‘mechanical’ (using sedimentation, septic, Imhoff and other types of tanks) biological (soil filtration, trickling filters and activated sludge) and chemical methods.

After the Second World War, two important innovations in sewage treatment took place in the Netherlands: the Pasveer Ditch and the Carousel.[97] In 1947, Pasveer of the Netherlands Organization for Applied Research (TNO) developed the so-called Oxidation or Pasveer Ditch, a simple and small-scale method for purifying waste water, based on the activated sludge process. The installation was, in normal circumstances, able to purify 80% to 90% of the organic waste of the sewage. It was relatively cheap, did not require too much supervising and was, for these reasons, better affordable for smaller municipalities than the existing installations. In 1953 and 1954, an experimental installation was built in *Voorburg*. In 1956, Pasveer gave a lecture for the KIVI, of which the text was later published in *De Ingenieur*. His ideas caught a lot of attention, but did not immediately met general enthusiasm. Later, his invention became more popular. Many Pasveer Ditches have been built in the Netherlands and in several foreign countries.

In the sixties, employees of the engineering firm *Dwars, Heederik en Verheij* (now DHV) developed a variant of the Pasveer Ditch, the so-called Carrousel. Pasveer Ditches were rather shallow and as they were used for larger and larger amounts of waste water, the space required for the system became a problem. It was the hydraulic engineer Klein, working at *Dwars, Heederik en Verheij*, who proposed a solution to the problem. He had the idea of using rotor aerators (*puntbeluchters)* to aerate and agitate the water in the Pasveer Ditch, so that the ditch could be made deeper. The idea turned out to be a success and the Carrousel was born.

Innovation Pattern

As the above shows, (foreign) research institutes and engineering firms played an important role in past innovations in sewage treatment. More recent innovations as well were usually developed by Dutch and foreign research institutes, including universities, and engineering firms.[98]

Until the seventies, research on sewage treatment was carried out by the RIZA and, after the Second World War, by the Netherlands Organization for Applied Scientific Research, TNO.[99] Since the early sixties, the universities - initially especially the Technical College Delft and the Agricultural College Wageningen - have increasingly carried out systematic research on sewage treatment.[100]

Since the seventies, an important role in the development and acceptance of innovations in sewage treatment has been played by the STORA. STORA is the abbreviation of *Stichting Toegepast Onderzoek Reiniging Afvalwater* (Foundation for Applied Waste Water Research) which since 1971 has coordinated the research of Water Boards and the other bodies responsible for sewage treatment. Research funded by the STORA is usually carried out by engineering consultants, the Netherlands Organization for Applied Scientific Research (TNO) and universities. Until recently, most of the research was directed at solving actual problems in sewage treatment, in many cases related to more stringent effluent standards. The STORA has become the authority on the feasibility of new treatment techniques.[101] Hence new techniques which have not been investigated or have been rejected by the

STORA are mostly seen as unproven and, hence, are seldom proposed by consulting engineers or accepted by Water Boards.[102]

While Water Boards are not immediately involved in bringing about most of the larger innovations in sewage treatment technology, they may be involved in smaller innovations and the regular design of sewage treatment plants. Sometimes, Water Boards have designed treatment plants largely by themselves. However, since most Water and Treatment have to design treatment plants only once in while, having a complete division being able to design such plants is mostly not cost-effective.[103] Therefore, Water Boards often hire a consulting engineer to carry out at least a part of the design task.
Innovations in sewage treatment are often developed and adopted in response to functional requirements. The Pasveer Ditch and the Carrousel are cases in point. Both innovations were developed in response to practical problems and guided by functional requirements of users (then still mainly municipalities). The important role of the STORA in the development and acceptance of innovations also underlines the point. Research is practice-oriented and guided by functional requirements of users (now Water Boards).
It should be noted that the innovation pattern also has mission-oriented characteristics. Increasingly, functional requirements of users derive from national policy documents and effluent standards. Nevertheless, Water Boards, and other instances responsible for sewage treatment, still have a certain autonomy in setting effluent standards. This is related to the fact that the (functions of the) waters on which sewage treatment plants discharge may vary from case to case, leading to different kinds of effluent standards.

E) Coastal Barriers

Country of focus: the Netherlands
Period: 1920's-1990's

Type of Innovating Firm

The main actor in the technological regime of coastal barriers is Rijkswaterstaat. This governmental agency is responsible for the centralized tasks in the field of water and road management in the Netherlands. Rijkswaterstaat was established in 1798.[104] In the twenties of the twentieth century, Rijkswaterstaat began to establish its own design and study departments.[105] In this way, Rijkswaterstaat could make its own design for hydraulic (and other) works. Until recently, engineering firms usually only played a limited role in the design of coastal barriers in the Netherlands. Designs are usually realized by building contractors. Sometimes, these firms are also involved in the design process.
Rijkswaterstaat is part of the central government. It can be characterized as a common good producer. It ‘produces’ expensive infrastructural goods. Coastal barriers are unique; designs have to be adapted to local circumstances. Maintenance plays an important role. Engineering firms and building contractors can be

characterized as specialized suppliers. They work closely together with their clients/principals, in this case Rijkswaterstaat.

Type of User

Expenditures for the design and building of coastal barriers are as a rule financed by the central government and have to be approved by parliament. Rijkswaterstaat usually plays an important role in the proposal and formulation of new coastal barrier projects. This agency is part of the (central) government. So, we can speak of the 'government as client.'

Innovations; Historically

The techniques of damming up rivers and tidal inlets have a long history in the Netherlands.[106] Many major past innovations and developments in this field originate in particular projects, including:

- the closure of the *Zuiderzee* between 1927 and 1932;
- the reclaiming of *Walcheren* in 1945-1946;
- the *Delta plan*. This plan was formulated after a storm flood disaster in 1953, killing 1835 people. The Delta Plan included the closure of some of the major tidal inlets in the south-west of the Netherlands. The plan was realized between 1954 and 1985 (for more details, see Chapter 5);
- the storm surge barrier in the *Nieuwe Waterweg* finished in 1997.

Most of these projects were carried out at the edges of what was considered technically feasible at the time.[107] Each project resulted in important innovations in coastal barrier design.

The *Zuiderzee* project was especially important because it gave an impetus to scientific research in relation to hydraulic engineering. Particularly, scientific research on tides and on the effects of barriers on tidal movements came to be carried out. This included research with hydraulic scale models as well as mathematical predictions.

The use of scale models to predict water movements in relation to hydraulic works had started in the late nineteenth and early twentieth century in France, England and Germany.[108] For the *Zuiderzee* project, hydraulic models were built in the garden of the Dienst Zuiderzeewerken in The Hague and at the university of Karlsruhe in Germany.[109] In 1927, Delft Hydraulics (*Waterloopkundig Laboratorium*) was established; a few years later Delft Geotechnics (*Grondmechanica Delft*) followed.[110] Both research institutes have come to play an important role in the regime of coastal barriers.

The physicist Lorentz played a major role in the development of mathematical methods for the prediction of tidal movements.[111] In 1918, Lorentz was asked by the government to chair the committee that was to predict the changing tidal movements due to the planned closure of the *Zuiderzee*. For this purpose, Lorentz developed mathematical prediction methods. In the thirties, these methods were also applied in the south-west of the Netherlands. The resulting insights later were used for the Delta plan.

The second of the above-mentioned projects, the reclaiming of *Walcheren*, was especially important because it meant the introduction of a new closing technique: the use of caissons or pontoons.[112] At the end of the Second World War, *Walcheren* had been intentionally inundated by the Allied Forces. The closure of the breaches in the dikes, of which the tide had taken possession, was technically very difficult.[113] Not because of the mere scope of the works, but because of the depth of the dike breaches and the strong tidal currents. The more traditional closing materials used for the *Zuiderzee* closure like bushwood, bolder clay and sand were not sufficient. The solution was found in the use of caissons, which were floated to the place of closure and then sunk. Such caissons or pontoons had already been used by the Allied Forces for the invasion of Normandy.
The reclamation of Walcheren was not only important in terms of techniques used, but also in terms of scientific and empirical research. According to Ferguson, the reclamation of Walcheren laid the ground for close cooperation between field research, mathematical calculations of tides and model research.[114]

The *Delta plan* implied innovations, both in an organizational and a technical sense.[115] Organizationally, it implied a departure from the existing and well established decentralized system of dike and water management in the Netherlands.[116] The Delta Plan required the management of a large project organization for design and construction. To design and build the Delta Works, a special Delta Department was established at the Rijkswaterstaat.
The Delta Plan required technical innovations too. In the fifties, it was not yet known how the planned closures could be carried out. Of course, there was relevant experience due to the closure of the *Zuiderzee*, the reclamation of *Walcheren* and the restoration of the dikes after the storm flood. Also the closure of the *Brielse Maas* (1950) and the *Brakman* (1952) provided useful experience.[117] This experience was, however, not enough to carry out the technically more difficult Delta Plan. Therefore, the Delta Plan required extra research efforts. Research had to be done on tidal movements, geotechnics and materials and constructions.[118] A new hydraulic research department was founded within Rijkswaterstaat and special hydraulic scale models were built.[119]
To enable organizational and technical learning and the required innovations, it was decided to build the Delta works from small to large, making it possible to learn optimally from the experience gathered. This institutionalization of technical and organizational learning later became known as the Delta School.[120]
Technically, especially the storm surge barrier in the *Oosterschelde* required the development and use of still new, and sometimes unproven, technologies and working methods.[121] (The decision to build a storm surge barrier was the result of a process of transformation described in Chapter 6). One of the most persistent technical problems in the design and construction of the storm surge barrier was the foundation of the barrier. Eventually, it was decided to compress the sand bed on which the barrier was to be built. For this goal a special ship was developed. On the

compressed sand beds, special prefabricated mattresses were laid with another specially developed ship.
For the design of the storm surge barrier, a probabilistic approach was (partly) followed.[122] This implies that for each component (including human control) the probability of failure is calculated and integrated into a calculation for the probability of failure for the complete installation. The probabilistic approach deviates from a traditional safety approach because the failure requirements for single components are dependent on their role in the complete installation. The probabilistic approach makes it possible to reach the same overall probability of failure in a more cost-effective way, at least that is the claim. In the case of the *Oosterschelde* storm surge barrier, the design was not completely based on a probabilistic approach, but the design of the storm surge barrier in the *Nieuwe Waterweg* is.

Innovation Pattern

Innovations in coastal barrier design are usually generated in specific projects. For each of these projects, a mission was formulated by the central government and Rijkswaterstaat. These missions were in such a way formulated that each of the mentioned projects was carried out at the edges of what was considered technologically feasible at the time.[123] So in each project, particular technical innovations had to be achieved. Because these innovations derived from specific missions formulated by Rijkswaterstaat or another governmental agency, we can speak of a mission-oriented innovation pattern.
This innovation pattern is also reflected in the existing division of design labor. As a rule, Rijkswaterstaat is responsible for the design of large hydraulic projects like coastal barriers.[124] Part of the design activities may be carried out by engineering firms. The actual execution of the works is mostly contracted out to building contractors via tenders.[125] Construction activities are usually supervised by Rijkswaterstaat. Research for specific projects is both carried out by the study departments of Rijkswaterstaat and independent research institutes like Delft Hydraulics.
Specific projects sometimes show some exceptions to this division of labor.[126] For the *Zuiderzee* project, a special governmental agency was established besides the Rijkswaterstaat.[127] The role of the contractors as well was somewhat different from the picture sketched above. Contractors were not contracted via separate tenders for each part of the project but via a more encompassing contract.[128] Nevertheless, also the *Zuiderzee* project reflected *grosso modo* the existing division of labor. The way in which contractors were contracted was seen as an exception considered acceptable, even necessary, given the scope and the difficulty of the closure. A governmental agency (albeit not Rijkswaterstaat in this case) was responsible for the design activities and the supervision of the works.[129] The mission for the project was formulated by government and parliament.
The Delta Plan also shows some exceptions to this division of design labor. In this case, close involvement of experts from outside the Rijkswaterstaat was deemed necessary. This was especially true for the largest and technically most difficult closure, that of the *Oosterschelde*. In that project, contractors, dredging companies

and engineering firms would eventually become closely involved in the design and construction process.[130] This was considered 'extraordinary' at the time, but deemed necessary given the (technical) complexity of the design task.[131]
The storm surge barrier in the *Nieuwe Waterweg* was designed by engineering firms and building contractors. Rijkswaterstaat only formulated the requirements. In this case, the barrier was built for a price fixed beforehand.
Despite their differences, all these divisions of labor represent a mission-oriented innovation pattern. The formulation of design requirements and criteria is based on a centrally formulated, politically accepted mission. This mission sets the agenda for a bundle of technical tasks and a number of 'planned innovations.' The government, *i.c.* (at least in most cases) Rijkswaterstaat acts as principal. Rijkswaterstaat or another governmental agency is closely involved in the design process (except for the *Nieuwe Waterweg* project). While engineering consultancies and contractors are sometimes directly involved in the design and construction process, Rijkswaterstaat is usually able to formulate the boundaries within which other actors could contribute to the design. The same applies to R&D activities. These are partly carried out by Rijkswaterstaat and partly by research institutes like Delft Hydraulics and Delft Geotechnics.

F) Waterside Banks Protections[132]

Country of Focus: the Netherlands
Period: 1960's-1980's

Type of Innovating Firm

Waterside banks protections are usually designed by the administrator or owner of the waterside bank in cooperation with engineering firms like Haskoning, TAUW, Heidemij, Oranjewoud, Grontmij, Witteveen + Bos and DHV. Engineering firms may be contracted by bank administrators either for their expertise knowledge or as additional working force.
The construction of the bank will, as a rule, be contracted out to a building contractor. In principle, contractors are not involved in the design process of the bank. Nevertheless, they may influence the design or the final construction built.[133]

Type of User

Waterside bank protections are ordered by the administrator of the bank. A host of actors may act as administrator: *dienstkringen* of Rijkswaterstaat, Water Boards, provinces, municipalities and private persons and (conservationist) organizations. Expect for the smaller waterways, most waterways are administered by the 'government as client.'
Waterways with national (mainly shipping) functions are as a rule administered by the central government. In practice, these waters are administered by *dienstkringen* which in turn are part of the regional directorates of Rijkswaterstaat. Most *dienstkringen* have their own technical department which is responsible for the

design, construction and (technical) maintenance of bank constructions, and other objects like sluices and bridges.[134]
Dienstkringen are relatively independent units within Rijkswaterstaat. Nevertheless, they have to carry out the policy of the regional directorate of Rijkswaterstaat of which they are part. Today, the regional directorates have to formulate a regional management vision (*regionaal beheersplan*) for their area. *Dienstkringen* will base their plans for (new) bank designs on this vision.[135] Regional directorates in turn will partly base their management vision on policy goals formulated by Rijkswaterstaat and in relevant governmental documents.
Waterways with an important regional function are mostly administered by provinces. Provinces now usually formulate policy plans for the maintenance of their waterways. Design of bank construction has to fit in such plans.
Smaller waterways which have an important function with respect to water transport and water level regulation are mostly administered by Water Boards. They now also often formulate policy plans. Water Boards have to comply which the (national) *Third Memorandum on the Water Economy* of 1988/1989.[136]

Innovations; Historically

Waterside bank protections are designed in an artisanal way. Innovations are often based on developments in construction materials and building materiel.[137] Materials which have become used in the course of time for waterside bank constructions include natural materials (stone, wood), rubbish, prefabricated concrete blocks, prefabricated mattresses, bituminous materials (asphalts) and synthetic materials.[138] Some of these materials were applied as spin-off of specific projects in related technological regimes - like those of dikes and coastal barriers - where more extreme requirements are posed. Solutions developed for more extreme circumstances sometimes turned out to be more cost-effective for waterside banks constructions.[139] An example is the Delta Project (regime of coastal barriers). Synthetic mattresses, which were developed for the foundation for the storm surge barrier in the *Oosterschelde*, were later applied in waterside bank constructions.
Innovations in waterside bank design also derive from more extreme requirements for waterside bank constructions. Important were, for example, developments in shipping leading to heavier loads on bank constructions.
In the same period that new types of constructions were developed in response to more extreme functional requirements, more systematic research came to be done on bank constructions and comparable hydraulic constructions.[140] Such research was, and is, done by instances like the Department of Civil Engineering of Rijkswaterstaat, the Technical University of Delft, and the research institutes Delft Hydraulics and Delft Geotechnics. These institutes carry out technical-scientific research on, among other things, the strength of constructions and materials. Delft Hydraulics has investigated - since the seventies - the loads on banks due to shipping in waterways.[141] This also included investigations of the stability of bank constructions. This research has resulted in the computer program DIPRO that can be used to dimension bank constructions.
Since the early sixties, associations of contractors have become more active with respect to the design of hydraulic works like waterside banks.[142] Partly, this shift was

due to need for new working techniques, methods and materials owing to the Delta Plan. This implied a more active role for the contractors.[143] The *Nederlandse Vereniging Kust- en Oeverwerken*, an association of building contractors active in the area of coastal and bank constructions, for example, established a Technical Committee and initiated research projects.[144]
A final actor that is important for research on bank constructions is the *CUR (Civieltechnisch Centrum Uitvoering Research en Regelgeving)*. The CUR is a foundation coordinating civil engineering research and formulating rules and norms. The latter are formulated in cooperation with the NNI, the *Netherlands Institute for Normalization*.

Innovation Pattern

Several actors have initiated innovations in waterside bank protections, including building contractors, suppliers of construction materials, research institutes and the actors directly involved in the design of bank constructions, *i.e.* bank administrators and engineering firms. Many actors can initiate innovations in waterside bank design due to the rather artisanal way of designing waterside bank constructions. It is relatively easy to think out a new construction or to apply new materials.
Usually, innovation is guided by functional requirements posed. In principle, these requirements are specific for the particular situation or project. Innovations achieved in specific circumstances - sometimes in other technological regimes - may later be applied in other circumstances.
Nevertheless, a pattern is discernible in the way in which innovations are generated and adopted. This is due to the fact that research and normalization activities - especially by instances like the CUR and Rijkswaterstaat - are often based on more generalized requirements. The development and acceptance of particular innovations are, therefore, related to generalized requirements as formulated by Rijkswaterstaat and the CUR.
Rijkswaterstaat is, to some extent, able to formulate a mission for the regime of waterside bank constructions. A serious amount of the research on waterside banks is carried out or commissioned by the Civil Engineering Department of Rijkswaterstaat. These activities are guided by missions formulated by the central board of Rijkswaterstaat. The same applies to design and maintenance activities of de *dienstkringen* of Rijkswaterstaat. *Dienstkringen* have to comply with policy plans formulated higher in the organization and by the government. Moreover, *dienstkringen* depend for technical and financial assistance on the central departments of Rijkswaterstaat. Larger maintenance and (re)construction schemes for banks have to be approved by the central board of Rijkswaterstaat.[145] Rijkswaterstaat centrally formulates - in cooperation with the Ministry for Transport and Communications - several-year plans for the (re)construction of waterside banks.[146] Dienstkringen further depend on the Civil Engineering Department of Rijkswaterstaat for technical advice if they cannot solve particular technical problems. The Civil Engineering Department also acts as clearinghouse for innovations.

The central organs of Rijkswaterstaat then have some control over R&D and design activities and, so, over the development and adoption of innovations. Obviously, this mainly applies to waterside bank constructions for waterways administered by Rijkswaterstaat. Other administrators of waterways are more autonomous than *dienstkringen* of Rijkswaterstaat. In these cases, innovation will be more user-driven. The CUR will often play an important role in the development and acceptance of innovations. Nevertheless, also in the case of waterways administered by Water Boards, innovation will have some mission-oriented characteristics because Water Boards are part of the central government and have recently come to comply with centrally formulated policy goals and documents.[147]

G) Aero-engines[148]

Country of focus: world-wide
Period: 1910's-1990's

Type of Innovating Firm

The market of civil aero-engines is dominated by three companies: Pratt &Whitney (P&W) and General Electric (GE) from the USA and Rolls Royce (RR) from England.[149] Besides there are a number of producers of smaller aero-engines like Snecma, Allison, Textron Lycoming and Garrett, and companies mainly active as suppliers or subcontractors like MTU, BMW and the consortium Japanese Aero Engines (JAE).[150]

Aero-engine producers are large science-based firms. Internal and external R&D are main sources of technological innovation, and R&D know-how is one of the means of appropriation. The history of the aero-engine industry is characterized by mergers and growing international collaboration. This tendency is partly the result of technological developments.[151] Development cost for new aero-engines, corrected for inflation, has been steadily rising[152], which makes it hard for the smaller companies to survive independently.[153] Also, the three large aero-engine producers are affected by rising development costs, long development times and high commercial risks.[154] The development of a new aero-engine may now cost more than one billion dollars.[155] This has led to mergers, takeovers and the establishment of commercial constructions like alliances and risk-sharing co-production agreements, between the large three and the smaller aero-engine companies.[156] Such commercial constructions have the advantage that development costs and risks are shared. Other motives for such constructions are: getting market access to different regions or countries and getting access to technologies or specialized capabilities.

Many governments provide ample financial resources for the aero-engine and aircraft industry.[157] Subsidies for (basic) research and testing are common in all manufacturing countries. Direct support of aero-engine and aircraft companies is more controversial. It is more common in Europe than in the United States.[158] In the USA, however, companies profit from governmental funds and rules in more indirect ways, *i.e.,* via defense contracts, protectionist and export promoting measures.

Type of User

The market for aero-engines is closely related to that of aircraft. Civil aero-engines are bought by either the aircraft manufacturer or the airline. Until the end of the sixties, aircraft and aero-engine were mostly seen as one entity.[159] The aircraft manufacturers chose an engine for each type of aircraft and sold the engine and aircraft together to an airline company. In the late sixties, this situation began to change. Nowadays, airlines can mostly choose among several aero-engines for each type of aircraft.[160]

Perceptions about what kinds of aero-engines aircraft manufacturers want to use (in the future) play an important role in aero-engine design and development.[161] Aircraft and aero-engine design are related in terms of engine requirements and technical characteristics. The market for aircraft much resembles that of aero-engines.[162] Technical innovation and development play an important role in competition. Development costs tend to rise. Markets have a cyclic nature. Their history is characterized by concentration and merger.[163]

Both aircraft manufacturers and airlines are professional users. Via them, a host of other actors influence the formulation of criteria and requirements for aero-engines, including airports, pilots, travel agencies and passengers. Governmental and semigovernmental bodies as well play a role in the formulation of requirements for aero-engines. Most countries have (semi-)governmental aviation agencies, which formulates minimum design requirements and certify aircraft. In the certification process, the national aviation agency checks wether an aircraft fulfils a number of national, and international, requirements.[164] These requirements mainly concern safety but may also relate to emissions and noise. In most countries, each new aircraft design and each individual aircraft has to be certified. Examples of aviation agencies are the Federal Aviation Agency (FAA) in the USA and the *Rijksluchtvaartdienst* (RLD) in the Netherlands.

Finally, several international organizations try to harmonize national and international rules for aircraft.[165] These organizations include the Joint Aviation Authorities (JAA), an organization of European aviation authorities, the International Civil Aviation Organization (ICAO), of which many countries are members and the European Aviation Conference (ECAC), the European counterpart of the ICAO.

The major design criteria for aero-engines are performance, reliability, durability and maintainability. While some of these requirements may be overlapping, other may contradict each other in concrete cases.[166] Hence, tradeoffs have to be accepted, of which some are related to meeting the overall requirements for aircraft.[167]

Innovations; Historically

Analysts of the technological development of aircraft and aero-engines have distinguished historically separate phases of innovation in aircraft and aero-engines.[168] The basic idea is that now and then more radical departures from existing technology take place, followed by periods of more calm, incremental innovation. Typical phases of innovation in civil aviation are:[169]

- 1910's: early flight; first (wooden) airframes combined with aero-engines deriving from automobile applications (Otto-engines). Engines not very reliable.

- 1930's: development of well-streamlined all-metal skin planes with more powerful and reliable piston engines-propellers. Innovations like the variable pitch propeller. DC-3 as prototypical for new generation.

- Late 1950's and early 1960's: narrow-body jet aircraft with swept back wings and turbojets or low-bypass turbofans as engines. Aircraft types like the Boeing 707 and the DC-8.

- Late 1960's and early 1970's: wide body aircraft with high bypass turbofans. Aircraft types like the Boeing 747, DC-10, L1011.

The four phases of innovation each relate to a new generation of aircraft and aero-engines. Within these phases more incremental innovations may also come in successive generations.
Each of the four phases witnessed the coming together of new civil aero-engine designs with new civil aircraft designs and new technological functions. The functions typical for the four phases can be specified as flight, reliable fligh, efficient flight and cheap flight.[170] In some of the mentioned phases, the largest innovations took place in aircraft design, as in the thirties with the all-metal skin airframes. In other cases, the aero-engine was most radically redesigned, as with the turbojet and the low-bypass turbofan. In some cases, innovations derived from the military domain, as with the turbojet. In other cases, innovations originated in the civil domain.[171] Often, the initial ideas for next generation designs seem to have come from government financed research institutes.[172] Often, they were only adopted after new firms had entered the market and introduced the innovation.[173]
Developments in science and R&D played a main role in the mentioned innovations in aero-engines. A typical example is the development of the turbojet, which was based on a presumptive anomaly.[174] The civil turbojet was subsequently developed from its military predecessors. Also, the development of low- and high-bypass turbofans heavily hinged on scientific and technological developments.

Innovation Pattern

There is evidence that many major past innovations in aero-engine and aircraft originate outside the established aircraft and aero-engine companies.[175] Government financed research institutes are in a number of cases an important source of innovation. Most countries in which aero-engines or aircraft are produced, have national R&D laboratories and test facilities. Prominent among them are the NASA aircraft laboratories Langley, Ames and Lewis. Research at national laboratories is financed by industry and by national governments. Some countries coordinate their research internationally. An example in Europe is Germany, England and France, which coordinate part of their research through GARTEUR: the Group for Aeronautical Research and Technology in EURope.[176]Also, related regimes of military technology are sometimes an important source of innovation in civil aero-engine design.[177] The turbojet is a case in point. The civil turbojet derived from its military predecessors.

Typically, innovations in aero-engine design start with R&D and developments in military aviation. This subsequently may lead to presumptive anomalies or promises, which may become shared by aero-engine companies, which further develop the technology.
One might wonder how such promises become shared by aero-engine companies. Competition plays a role. It may be crucial for aero-engine companies to have a number of promising technologies on the shelf might aircraft manufacturers or airlines express a need for them. However, developing an innovation as first is not always attractive given the large development costs and high commercial risks. The large size of the aero-engine companies and the various existing coproduction collaborations may alleviate these disadvantages somewhat and so stimulate innovation.[178] However, empirical evidence suggests that many major past innovations were first introduced by new firms entering the market.[179] Only later the innovations were taken over by the established companies and adopted at a large scale.

So, the regime of aero-engines has an R&D-dependent innovation pattern, in which innovation takes place in successive generations. Next-generation designs are based on technological promises and presumptive anomalies arising from developments in science, R&D and related regimes of military technology and R&D. These promises may subsequently be picked up by (new) aero-engine companies, which develop them to full-fledged innovations and align them to (new) functions of aero-engines. This is not to say that each technological promise or presumptive anomaly is turned into a successful innovation. A typical example of a technologically successful but commercially failed innovation in aircraft is the Concorde. In the sixties, Super Sonic Transport (SST) aircraft was conceived as one of the promises of the future (alongside with vertical and short takeoff and landing (V/STOL) planes).[180] The Concorde was to make true this promise, but when it entered service, it was not only futuristic, but outdated as well. It had a modern outlook and was a major technical achievement. It could, however, not meet a number of design requirements and criteria that had become more important over the years, especially with respect to fuel consumption and noise. Moreover, a new alternative had become available - wide body aircraft with high bypass turbofans - that scored better at most design criteria, except speed.

H) Nuclear Reactors

Country of focus: USA
Period: 1945-1970's

Type of Innovating Firm

In the USA, nuclear reactors were initially produced by two large companies from the electric industry: General Electric and Westinghouse.[181] Later, they were joined by firms like Babcock & Wilcox and Combustion Engineering (now part of the consortium ABB) and Gulf-General. Of these companies, only the latter was not

yet a major supplier to the electric utility market. This is also the only company that produces gas-cooled reactors.[182] The other companies all produce Light Water Reactors (LWRs); GE of the boiling water type; the others of the pressurized water type. (For a description of the different reactor types, see Chapter 7).
Worldwide, the largest reactor vendor is ABB. Other major reactor vendors include Siemens (Germany) and Framatome (France). Apart from the reactor vendors, also smaller (supplying) firms and research institutes play a role in reactor research, development and design.
The nuclear reactor vendors are large science-based firms. Like the producers of aero-engines, they are confronted with increasing development costs and high commercial risks. Reactor vendors have used several commercial constructions to share risks and gain market access in other regions of the world.[183] First, some reactor vendors that operate internationally, like ABB, own a number of reactor vendors in various countries. Second, international joint ventures have been created like NPI (Nuclear Power International) in which Siemens and Framatome cooperate. Third, international coproduction agreements and consortia have been established.

Type of User

Nuclear reactors are an important part of nuclear plants, which are ordered by utilities. Such utilities may be government-owned, semi-governmental or private. Utilities may thus be characterized as professional users or the government as client. In the USA, most utilities are private. Public Utility Commissions (PUCs) and the Federal Regulatory Commission control the electricity rate and in this way influence investment returns and, indirectly, reactor choice.
Most countries have governmental committees or bodies overseeing the development of nuclear energy and nuclear reactors. In the USA, this is the Atomic Energy Commission (AEC). Initially, the AEC was both to promote nuclear energy and to regulate it. In 1974, the AEC was split leading to the foundation of the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC). The NRC certifies reactor design and individual reactors, primarily with respect to safety requirements.
Internationally, safety regulations are issued and harmonized by the International Atomic Energy Agency (IAEA), which was established in 1957.[184] The IAEA also promotes the use of civil nuclear energy.

Innovations; Historically

Like innovations in aero-engine design, the major innovations in civil nuclear reactors were based on earlier developments in military technology, science and R&D. Below, I will describe reactor development until the seventies, focusing on the USA. In this period, research and development of nuclear reactors concentrated on the Light Water reactor and the breeder reactor.

After the Second World War, the USA tried to keep its monopoly on the atomic bomb.[185] It was recognized by the Americans that the development of civil atomic reactors might result in the proliferation of nuclear arms, since military and civilian applications rested, to an important extent, on the same technologies and materials.

The 1946 US Atomic Energy Act, therefore, gave the US government exclusive authority over the development and use of atomic energy and strictly circumscribed cooperation with other countries.[186]
The 1946 bill also encouraged the development of peaceful applications of atomic energy. The governmental organization that became responsible for this development was the Atomic Energy Commission (AEC). The functions of the AEC were circumscribed in the 1946 bill; most of them were military, some of them civilian. The early civilian efforts of the AEC concentrated on so-called breeder reactors, reactors which could produce both heat for power and new fissionable materials. At that time a shortage of fissionable products was feared. Moreover, the produced fissionable materials would be useful for military applications.
Early AEC efforts also included other types of reactors besides the breeder reactor. One of the projects was the development of what is nowadays called the Light Water Reactor (LWR). This reactor was initially developed for submarine propulsion and, therefore, had to be compact. As a result, the LWR had a high power density.
The LWR submarine project under the supervision of the later admiral Rickover was very successful. Therefore, the LWR design was chosen in 1952 when the AEC was considering a major power reactor development project. Westinghouse, which had played an important role in the submarine project, was invented as prime design contractor for the project.[187] The AEC funded the project. In 1957, the first LWR was built at Shippingporte.[188] The building of the Shippingporte reactor greatly enhanced the commercial prospects of the LWR over other designs in the USA.[189]

By 1953, the US moratorium on nuclear technology and materials had clearly not prevented the proliferation of nuclear arms. The Soviet Union had brought to explosion its first atomic bomb in 1949. It was followed by England in 1952. The 'anarchistic' development of nuclear reactors in a number of countries made the American government anxious for further proliferation. The USA decided to revise its policy with respect to nuclear technology. The 'Atoms for Peace' program was launched by president Eisenhower on the eighth of December 1953. This program aimed at cooperating with friendly nations to enhance the development of (civil) nuclear energy. In turn, these countries had to promise to use nuclear technology only for civilian purposes and to allow American safeguards. In this way, it was hoped to stop the development of 'uncontrollable' nuclear capacity.[190]
The 'Atoms for Peace' program had consequences both for the development of civil nuclear reactors within and outside the USA. Within the USA, it had the consequence that the US Atomic Energy Act was changed in 1954 as to make possible private ownership of nuclear plants. Firms like General Electric (GE) and Westinghouse now began to develop LWR designs.[191] Outside the USA, the program favored the LWR as well.

Contrary to the USA, where many of the initial efforts concentrated on the LWR, in Europe gas-graphite reactors were more favorite in the fifties.[192] Thanks to British and French efforts, gas-graphite reactors were considered more advanced in most of Europe. Therefore, it seemed natural that England or France would take the lead in European reactor development. However, this did not happen.

In 1958 the just established EURATOM (the European Organization on Atomic Power) signed a Joint Agreement with the USA for a reactor and research program.[193] For the Americans, this agreement was a logical consequence of the 'Atoms for Peace' program. European countries like Germany, the Netherlands and Belgium favored cooperation with the Americans. France was more hesitating but, on the other hand, did not want to offer its gas-graphite technology as base for a Euratom program. England was not a member of EURATOM.[194]
Since the French and Britains did not offer their gas-graphite technology, the Joint Agreement was based on American LWR technology. This created the impression in Europe that LWRs were technologically at least at equal footing with the gas-graphite reactors.[195] This impression was further fed by the fact that the LWR won two important European design competitions in these years.[196] Thus, by the early sixties, the LWR was becoming increasingly popular in Europe.

By 1962, 50 nuclear plants were generating electricity worldwide.[197] None of these plants produced electricity cheaper than conventional plants, partly because conventional plants had become more efficient.[198] In 1962 the nuclear reactor regime could not yet compete on purely economic grounds with the other existing technological regimes to produce electricity. In a few years, however, the perceived prospects of nuclear power changed dramatically. This dramatic change was initiated in the United States, and meanwhile brought the dominance of the LWR.
In the USA, the Atomic Energy Commission was a main promoter of nuclear technology. Although, the AEC believed that the commercialization of nuclear power was a task of private industry, it facilitated this commercialization in several ways.[199] In 1957, for example, the Price-Anderson Act was passed. This act placed the burden of liability for nuclear accidents on the government.[200] This opened the way for industry and the utilities to become engaged in nuclear power. In 1962, the AEC published a report in which it stated that the costs of electricity generated by LWRs had seriously declined in the past few years. Nuclear power now was believed to be 'on the threshold of economic competitiveness' and it could 'soon be made competitive in areas consuming a significant faction of the nation's electrical energy.'[201]
Already in 1963, the AEC prophecy seemed to come true. In that year, the Jersey Central Power & Light Company announced the purchase of an LWR on purely economic grounds. After this so-called Oyster Creek deal, it was increasingly believed that nuclear energy was economically competitive and many orders for nuclear reactors were placed. For many, nuclear power now meant Light Water Technology. Also outside the USA, the Oyster Creek deal and the subsequent bandwagon market created the impression that LWRs were more economic than other types of nuclear reactors. Although some countries like Canada and England stuck to their own reactor types, other countries like Sweden switched to the LWR.[202]
France tried to forestall American hegemony by active promotion of its gas-graphite technology, but it could not turn the tide. In 1969, also France decided to switch to LWR technology.[203]
The sixties did not bring a complete triumph of the LWR in the USA. The AEC decided to concentrate its development efforts on the expected next generation of

nuclear reactors: the breeder reactor.[204] There are two main reasons for this decision of the AEC. First, the AEC believed that the refinement of the LWR design and the resolution of safety issues was to be carried out by industry itself. Second, the AEC did not see the LWR as the most optimal long-term option. LWRs were wasteful of nuclear fuel and operated at relatively low temperature, which made them thermodynamically not the most efficient type of reactor.

The second reason implies that the AEC envisaged a presumptive anomaly in respect to the LWR. It was expected that LWRs would eventually not be efficient enough and would be plagued by a shortage of nuclear fuel. Both problems could in principle be solved by the breeder. This vision of the AEC was shared by other government agencies and scientists.[205]

Eventually, the breeder reactor would not become a success (at least until yet). In the USA, and elsewhere, it lost much of its appeal together with nuclear energy. Since the seventies, the nuclear reactor regime has been plagued by problems like lengthy licensing processes, rising costs and public doubts (for more details, see Chapter 7).

Innovation Pattern

The innovations described above fit in a R&D-dependent innovation pattern. As with civil aero-engines, the technological promises for new generations of nuclear reactors originated in military R&D and in civil research done at government research institutes. The first civil nuclear reactors were developed from scientific insights and technological applications first developed during the Manhattan project for the atomic bomb and later during the submarine project of Rickover. Scientists and technologists from government (research) institutions and, later, from companies that had partly been involved in the earlier projects, played a paramount role in developing technology for nuclear reactors. The breeder reactor was based on a presumptive anomaly deriving from technological and scientific insights. In its further development, research institutes played an important role. The same holds for new types of reactors, which are now under development (for more details, see Chapter 7).

Notes to Appendix 3

1 The regime description is mainly based on S. Östlund & R. Larsson, 'The Greening of Strategic Alliances' (1991), Paper presented at the 11th Annual International Conference, Strategic Management Society, Toronto Canada, October 23-26, 1991; R. Schwartz Cowan, 'How The Refrigerator Got Its Hum,' in D. Mac.Kenzie & J. Wajcman (eds.), *The Social Shaping of Technology* (Milton Keynes: Open University Press, 1985), 202-218; R. Thévenot, *A History of Refrigeration Throughout the World* (Paris: International Institute of Refrigeration, 1979); R.B.J. Kemna, *Notitie koelkastmarkt t.b.v. het Wereldnatuurfonds* (1992), rapport Van Holsteijn en Kemna; H.O. Spauschus, 'Development in Refrigeration; Technical Advances and Opportunities for the 1990s,' *International Journal of Refrigeration*, 10(1987)5, 263-270, National Wildlife Foundation, 'Du Pont Freon Products Division' (1989), case study prepared by Foest Reinhardt; interview Lotz, 12-5-1994.

2 Thévenot, *Op. cit.*. In the USA, the production and sale of household refrigerators began to expanded quickly after the First World War. In 1921, 5,000 household refrigerators were produced in the USA. In 1929 the annual production of refrigerators was just as large as that of ice-boxes (800,000). Six years later, in 1935, 1.7 Million refrigerators were produced and 'only'

350,000 ice-boxes. By 1949, the annual production had further risen to 6.7 million. After the Second World War, Europe also caught up and finally surpassed the USA in the production of household refrigerators.

3 Östlund & Larsson, *Op. cit.*, 15; Kemna, *Op. cit.*, 2.

4 Miele does not independently produce household refrigeratis (J. Conrad, 'Greenfreeze: Environmental Success by Accident and Strategic Action,' in M. Jänicke & H. Weidner (eds.), *Successful Environmental Policy; A Critical Evaluation of 24 Cases* (Berlin: Wissenschaftszentrum für Sozialforschung, 1995), 364-378).

5 In 1994, AEG was bought by Electrolux.

6 Östlund & Larsson, *Op. cit.*.

7 Östlund & Larsson, *Op. cit.*, 15-16.

8In 1950, 3% of the French households had a refrigerator; in 1975 90%. In 1952, 8-10% of the German households had a refrigerator; in 1975 90-95% (Thévenot, *Op. cit.*, 347-348).

9 The commercial manufacture of refrigeration equipment had started around 1875 (Thévenot, *Op. cit.*, 64-65). Around 1900, an infrastructure for the exchange of information on refrigeration (technology) began to crystalize. Journals began to appear, associations and professional groups were formed, meetings and congresses were organized, instruction in refrigeration was established and numerous technical books were published (Thévenot, *Op. cit.*, 149-155). (Between 1875 and 1895 books on refrigeration were practically non-existent, but (technical) information was exchanged by, for example, memoirs to learned societies and articles in physical and mechanical journals). In 1908, the first International Congress of Refrigeration was organized. This congress led to the establishment of the International Association of Refrigeration, which was renamed as the International Institute of Refrigeration (IIR) in 1920. Short and good, in the early twentieth century a technological regime of refrigeration came into being. The household refrigerator was a product of this regime.

10 The other types were machines expanding pre-compressed air (air-cycle machines) and machine relying on the evaporation of water at reduced pressure (water-vapor machines). Until 1875, absorption machines were the most popular. After the introduction of compression machine using ammonia as refrigerant (before methyl ether had often been used), compression machines became increasingly popular (Thévenot, *Op. cit.*, 37-49).

11 Early in the twentieth century, it was clear that there might be a large market for a 'mechanical' household refrigerator. In the USA, domestic refrigeration by iceboxes was already widespread (Thévenot, *Op. cit.*, 172). However, a number of technical problems still had to be solved to develop a safe, automatic, reliable household refrigerator that could be mass-produced. Technically, these problems seem to have been as great for the absorption as for the compression machine.

12 Schwartz Cowan, *Op. cit.*.

13 *Ibid.*

14 *Ibid.*. Absorption machines may even have had some advantages. They worked on gas, whereas compression machines used electricity. This was an advantage because, until 1925, gas service was more widespread than electric service in the USA. Moreover, absorption machines were more silent, potentially easier to maintain and would probably be less costly in operation, especially in places where gas was cheaper than electricity. On the other hand, absorption machines required still a lot of development work and marketing, especially since the public feared the use of the toxic and flammable ammonia as coolant. (Ammonia with water was, and is, one of the most used coolants pairs in absorption refrigerating machines).

15 *Ibid.*.

16 Compression household refrigerators were initially often imported from the USA (Thévenot, *Op. cit.*, 174)

17 Thévenot, *Op. cit.*, 258.

18 *Ibid.*.

19 Thévenot, *Op. cit.*, 174.

20 Östlund & Larsson, *Op. cit.*, 14.

21 *Ibid.* According to Thévenot (*Op. cit.*, 173-174), CFCs were seldom used as coolant for quite some time. One reason was that their use introduced miscibility problems with the oils that were used to lubricate the compressor. This problem was partly solved at the end of 1950's with the introduction synthetic oils (Thévenot, *Op. cit.*, 253).

22 Östlund & Larsson, *Op. cit.*

23 Greenpeace, 'Greenfreeze; A Revolution in Domestic Refrigeration' (1996), Document retrieved from the WWW on 7-5-1996;
http://www.greenpeace.org/~ozone/greenfreeze/index.html, 6 pp.

24 National Wildlife Foundation, *Op. cit.*; The News Journal, August 25-28 1991, Reprint, 9.

25 Östlund & Larsson, *Op. cit.*

26 Kemna, *Op. cit.*, 3.

27 Spauschus, *Op. cit.*; Kemna, *Op. cit.*.

28 Öslund & Larsson, *Op. cit.*.

29The larger refrigerator firms also intentionally try to avoid to be too dependent on their suppliers by having more than one supplier for the more important parts of the refrigerator (Interview Lotz, 12-5-1994).

30 The regime description is mainly based on P.H.M. Eijssen, H.J. Bos, H.B. Duesman, *et al.*, 'Produktie van verf' (1992), RIVM (rapportnr. 736301128), RIZA (notanr. 92.003/28) en DGM; S. Meredith & T. Wolters, *Proactive Environmental Strategies in the Paint and Coatings Industry in Great Britain and the Netherlands* (Apeldoorn: TNO, 1994), TNO Report STB/94/022; B. van der Meulen, *Beoordelingsprocessen in wetenschap (Evaluation Processes in Science)* (Delft: Eburon, 1992), Proefschrift Universiteit Twente, 152-158; A.P.J. Mol, *The Refinement of Production; Ecological Modernization Theory and the Chemical Industry* (Utrecht: Van Arkel, 1995), 133-205; R.A. van de Peppel, *Naleving van milieurecht; Toepassing van beleidsinstrumenten op de Nederlandse verfindustrie* (Deventer: Kluwer, 1995), Proefschrift Rijksuniversiteit Groningen, 93-122; Programma Voorbereidings Commissie voor het IOP-Verf, *Meerjarenplan voor het IOP-Verf* (Uitgevoerd in opdracht van het Ministerie van Economische Zaken) (Leidschendam: Civi Consultancy, 1991); Programmacommissie OSV, *Evaluatie proefprojecten* (Civi Consultancy, 1989); CEPE (ed.), *VOC-Policy of the European Paint Industry* (Presented by CEPE at the first International Congress on Volatile Organic Compounds, March 1991) (Brussel: CEPE, 1991); *Verfkroniek* 1982-1996 and interviews (see Appendix 2).

31 Instead of linseed oil, sometimes varnish was used; varnish were produced by heating linseed oil with fossil resins.

32 Their number rose from 53 in 1850 tot 75 in 1890. Many of these companies were already active in the production of varnishes. See E. Homburg, 'Een bedrijfstak in verandering,' in H. Lintsen, *et al.* (ed.), *Geschiedenis van de techniek in Nederland (Deel IV)* (Zutphen: Walburg, 1993), 261.

33 *Chemisch Weekblad*, 49(1953), 606-607.

34 Interview Winkelaar, 15-8-1995. Van de Peppel estimates the number of production locations in the Netherlands to be about ninety to one hundred. Since a number of these locations are part of a larger company, according to him there are about sixty to seventy 'independent' paint manufacturers in the Netherlands (Van de Peppel, *Op. cit.*,97).

35 Mol, *Op. cit.*, 137.

36 Van de Peppel, *Op. cit.*, 100.

37 Until the seventies, the paint industry was largely national in scope (Mol, *Op. cit.*, 195) Since then, however, paint manufacture and sale have increasingly become international.

38 Q.I.L. Knight, 'VOC Reduction; Market Overview,' in CEPE (ed.), *VOC-Policy of the European Paint Industry* (Presented by CEPE at the first International Congress on Volatile Organic Compounds, March 1991) (Brussel: CEPE, 1991), 6-9). A number of smaller companies in Europe is probably not a member of CEPE.

39 In fact, the number of paint companies in the Netherlands is relative small and these companies are relative large compared with such countries like Italy, Spain and Portugal. In other Western European countries like German, Britain, France and Denmark, however, the

same pattern can be found as in the Netherlands (Mol, *Op. cit.*, 140).

40 Van de Peppel, *Op. cit.*, 98. Also other publications give this estimate. Peterse of Sigma, states that the market share of the world largest paint manufacturers in the Netherlands has risen from 65% in 1979 to 80% in 1988 (*Verfkroniek*, 66(1993)2, 24-25). These estimates probably include paints imported in the Netherlands from other large multinational paint companies beside Akzo and Sigma.

41 In 1994, Akzo merged with Nobel.

42 N. Nelissen, H. van Boxtel & M. Lemmen, *Beleidsstijlen van managers ten aanzien van het milieu; Een onderzoek naar beleidsstijlen van managers in de verf- en schildersbranche* (Zeist: Kerckebosch, 1991), 49-56.

43 On the history of paints and the (Dutch) paint industry see Anonymus, 'De historische ontwikkeling van de chemische industrie,' *Chemisch Weekblad*, 49(1953), 594-609; H. Brunner, 'Paint', in T.I. Williams (ed.), *A History of Technology (Volume VI)* (Oxford: Oxford University Press, 1978), 590-606; A. Hallema, 'Honderd jaar verf, 1848-1948; Gedenkschrift van de N.V. Vernis- en Verfwarenfabriek v.h. J. Wagemakers & Zonen Breda' (1948); E. Homburg, 'Industrie, chemie en milieu (1750-1815),' in H. Lintsen, *et al.* (ed.), *Geschiedenis van de techniek in Nederland (Deel IV)* (Zutphen: Walburg, 1993), 159-179; E. Homburg, 'Een bedrijfstak in verandering,' in H. Lintsen, *et al.* (ed.), *Geschiedenis van de techniek in Nederland (Deel IV)* (Zutphen: Walburg, 1993), 259-270; J.A. Lammers & J.W. de Wit, *Verf en verftoepassing* (Leiden: Spruyt, Van Mantgem & De Does, 1963); H. Roon, 'A Brief General History of the UK Paint Industry Part 1-12' (1985), appeared in *Pigment and Resin Technology* between January 1985 and December 1985, J.H. van der Steen, *200 jaar Sikkens* (Sassenheim: Akzo Coatings bv, 1991), J.H. de Vlieger, 'De ontwikkeling der Nederlandsche verfindustrie I-III' (no date), Unpublished manuscript; mimeo 16 pp; J.H. de Vlieger & E. Homburg, 'Loodwit,' in H. Lintsen, et. al. (ed.), *Geschiedenis van de techniek in Nederland (Deel IV)* (Zutphen: Walburg, 1993), 205-221.

44 Van de Steen, *Op. cit.*, 15-16.

45 Brunner, *Op. cit.*, 591-592.

46 Brunner, *Op. cit.*, 600-601; Van de Steen, *Op. cit.*, 21; Lammers & De Wit, *Op. cit.*, 373.

47 There are at least three reasons why nitrocellulose lacquers became popular by then. First, nitrocellulose lacquers had been technically improved in the course of time. For example, suitable solvents had been developed. Second, nitrocellulose was already produced by the explosives industry. After the First World War, this industry was looking for new applications of nitrocellulose. This industry could easily switch to the production of nitrocellulose for paints. Third, nitrocellulose lacquers dried fast and were easy to apply, which made them very attractive for the - then upcoming - car industry.

48 Lammers & De Wit, *Op. cit.*, 48 and 314.

49 Recent 'latex paints' little resemble the original latex paints, but the term is still generally used.

50 Brunner, *Op. cit.*, 604-605.

51 Production apparatus for the production of paints is merely imported from companies in Germany, Switzerland, England and the USA.

52 Mol, *Op. cit*, 176.

53 Interview Winkelaar, 15-8-1995.

54 A recent development is the use of computers. They are used in the design process in a number of ways. First for price control; computer make it easier to estimate the price of new products early in the design process. Second for simulations of for examples spraying techniques. Third for the storing of properties of raw materials and the systematic comparison of alternatives (statistical design).

55 This is, for example, the case with the test that is used to measure the viscosity of paints (Van der Meulen, *Op. cit.*, 153-154).

56 Systematic and often standardized tests are carried out by institutes like TNO Coatings and the Center for Surface Technology.

57 E.H. Ketelaars, *Historie van de nederlandse pluimveehouderij* (Barneveld: BDU, 1992).

58 R. Harrison, ‘Case Study: Farm Animals,’ in R.J. Berry (ed.), *Environmental Dilemmas: Ethics and Decisions* (London: Chapman & Hall, 1993), 118-135.

59 Interviews battery cage producers.

60 Interviews battery cage producers.

61 This description below is mainly based on Ketelaars, *Op. cit.*.

62 W.P. Blount, *Hen Batteries* (London: Baillière, Tindall & Cox, 1951), 13; E.H. Ketelaars, *Op. cit.*, 79; R. Harrison, *Animal Machines; The New Factory Farming Industry* (London: Vincent Stuart, 1964).

63 Blount, *op. cit.*, 13; R. Hartman and D.F. King, *Keeping Chickens in Cages* (Redlands, California: Roland C. Hartman, 1957),10.

64 Blount, *Op. cit.*, 15. Harrison, *Op. cit.*,40.

65 D. Bell, ‘The Egg Industry of California and the USA in the 1990's; A Survey of Systems,’ *World’s Poultry Science Journal*, 49(1993), 58-64.

66 P. Schenk, ‘Het nuttige dier,’ in M.B.H. Visser & F.J. Grommers (eds.), *Dier of ding; Objectivering van dieren* (Wageningen: Pudoc, 1988), 31-50.

67 O.A. Hanke, J.L. Skinner and J.H. Florea (eds.), *American Poultry History 1823-1973*, (American Poultry Historical Society, 1974), 33.

68 *Ibid.* In the Netherlands the first magazine devoted especially to poultry farming appeared in 1923 (Ketelaars, *Op. cit.*, 104).

69 P. Ubbels, ‘Onderzoek als grondslag van moderne pluimveehouderij,’ *Landbouwkundig Tijdschrift*, 73(1961)20 (1961), 968-987.

70 Ketelaars, *Op. cit.*, 158. In the text Ketelaars speaks about the percentage of farmers having more than 1000 chickens. However, from the table he uses and from the other numbers he gives, it becomes clear that he must have meant the percentage of chickens kept on farms with more than 1000 chickens.

71 Ketelaars, *Op. cit.*, 161.

72 Ketelaars, *Op. cit.*, 162.

73 Food conversion is the ratio between the weight of the (specialized) food that farmers feed their chickens and the weight of (sellable) eggs, that these chickens produce.

74 In laying batteries there are no ground-eggs, because the eggs when laid roll automatically from the floor (which is at a slope) onto an egg conveyor, which collects the eggs. In housing systems with slatted floors the chickens are supposed to lay their eggs in so-called laying-nests, which distribute the eggs to egg conveyors in order to collect the eggs. However, some small percentage of the eggs is not laid in laying nests but on the ‘ground,’ these eggs have to be collected by the farmer by hand. This work is much disliked by farmers because they have to bend down to pick up each egg.

75 Ketelaars, *Op. cit.*, 221.

76 Harisson, *Op. cit. 1993*.

77 Interviews battery cage producers; interview Van de Weerdhof, 24-5-1993; Interview van Niekerk, 19-10-1992.

78 Poultry research is also done at several Dutch universities, preeminently the Agricultural University at Wageningen and the Veterinary Faculty at the University of Utrecht.

79 Designing a new battery cage requires approximately one to two years. While almost all battery cages are very similar in their general lay-out, details may prove very important. An example is the floor of a battery cage, which is at a certain slope. As a result eggs role automatically onto an egg conveyor. If the wrong material is chosen for this ‘floor,’ the eggs will break while rolling down.

80 Interviews battery cage producers.

81 Rijksinstituut voor de Zuivering van Afvalwater, *50 jaar zuivering van afvalwater* (bevat bijdragen van diverse auteurs) (Den Haag: Staatsuitgeverij, 1970).

82 Rijksinstituut voor de Zuivering van Afvalwater, *Op. cit.*; W.A.H. Brouwer, 'De stichting bedrijfsonderzoek afvalwaterzuiveringsinstallaties,' *Water*, 46(1962) (1962), 65-67; D. Hillenius, *De geschiedenis van het Technisch Adviesbureau voor de Vereniging van Nederlandse Gemeenten* (Den Haag: VNG Uitgeverij, 1992), Speciale uitgave ter gelegenheid van het 75-jarig bestaan van DHV-Amersfoort; K.C. Zijlstra, 'Ontwikkelingen bij de centrale zorg voor de kwaliteit van het oppervlaktewater in Nederland,' *H_2O*, 9(1976)23, 479-483; interview Dirkzwager, 31-8-1994; interview Schutte, 7-8-1995; interview Van Selm, 15-12-1994.
In the fifties, the engineering firm *Dwars, Heederik en Verheij* had been the first to set up a laboratory, in which water samples could be analyzed in order to assess the operation of sewage treatment plants. It was also the first firm to design complete sewage treatment plants, instead of only the civil technical parts. Historically, *Dwars, Heederik en Verheij* had been connected to the Union of Dutch Municipalities. Also, the *Technisch Adviesbureau van de Unie van Waterschapsbonden* (Technical Consultant for the Union of Water Boards) - which was connected to the Union of Water Boards - set up a laboratory in the fifties. In the sixties and seventies more and more engineering firms began to design complete sewage treatment plants. In 1970, when the Dutch Pollution of Surface Waters Act (WVO) became in force, the role of the RIZA was more or less officially confined to that of advisor to Water and Treatment Boards.

83 *H_2O*, 17(1984)19, 421-425.

84 Interviews (see Appendix 2).

85 See, for example, N. Groeneveld, *Afvalwaterzuiveringstechnieken* (m.m.v. Dr. E. Nijhof, Ir. J. van Selm, Ing. S.A. Oldenkamp) (Zeist: Stichting Projectenbureau Industrieel Erfgoed, 1994), PIE Rapportenreeks.

86 C. Sneep, *Het Waterschapsbestuur; Kanttekeningen bij de ontwikkeling van het waterschap tot functionele representatie-democratie* (Deventer: Kluwer, 1980), dissertation, 72-74; A.C.J. Koot, 'Afvalwaterbehandeling en waterkwaliteitsbeheer; terug- en vooruitzien,' *H_2O*, 16(1983)19, 425-432. Before, Water Boards were only responsible for what is called *quantitative* water management and *passive quality* management. The latter included the formulation of requirements for water quality, but not the purification of waste water.

87 On the Water Boards see: B. de Goede, J.H.M. Kienhuis, J.G. Steenbeek, *et al.* (eds.), *Het Waterschap; Recht en werking* (Deventer: Kluwer, 1982); J.J. de Graeff, O. van der Heide, J.M.A.M. Mouwen, et. al., *Het Waterschap in kort bestek* (Den Haag: VUGA, 1990); C. Sneep, *Op. cit.*.

88 In 1947 the Provincial States of *Noord-Brabant* installed the *Dommel* Committee. The *Dommel* is a small river in *Noord-Brabant*, that had become heavily polluted. The *Dommel* Committee was to advice about ways to combat this pollution. On the basis of the report of the committee, the Provincial States decided to give Water Board *de Dommel* the responsibility for both passive and active water management in its area. Hence, the Water Board was to build sewage treatment installations, while the municipal authorities stayed responsible for the sewerage system. (Sneep, *Op. cit.*; Koot, *Op. cit.*).

89 This delegation has led to some controversies. The Union of Water Boards believed that sewage treatment should be a task of the Water Boards, which would then combine the quantitative and qualitative (passive as well as active) water management. A number of municipalities, especially those who had experience in sewage treatment, did not want to give up this task. As a result, in some rare cases, municipalities have stayed responsible for sewage treatment. *Cf.* P. Smeele & P. van Eck., 'De afvalwaterzuiveringsinstallatie in de Dokhaven,' in M.L. ten Horn-van Nispen, M.L. Lintsen & A.J. Veenendaal (eds.), *Wonderen der techniek; Nederlandse ingenieurs en hun kunstwerken 200 jaar civiele techniek* (Stichting Historie der Techniek) (Zutphen: Walburg, 1994), 184-196). On the conflicts with respect to the responsibility for sewage treatment, see also *H_2O*: 4(1971)4, 91; 4(1971)23, 545-555 and 6(1973)2, 44-44 and 49; *Waterschapsbelangen*: 60(1975)20, 335-336 and 60(1975)18, 307-308.

90 Amsterdam already in 1930 employed an adjunct chemical engineer (Van der Zee) and made study trips to, for example Germany (*H_2O*, 26(1993)6, 142-147). Amsterdam was, however, an exception. Many cities were even lacking qualified personnel to operate the built sewage treatment plants, resulted in many mal- or non-functioning plants (H. van Zon, *Een zeer onfrisse geschiedenis; Studies over niet-industriële vervuiling in Nederland, 1850-1920* (Groningen: Rijksuniversiteit Groningen, 1986), 242).

91 *H_2O*, 3(1970), 712,713; Koot, *Op. cit.*; Groeneveld, *Op. cit.*; Sneep, *Op. cit.*; De Goede *et al.*, *Op. cit.*; Zijlstra, *Op. cit.*; Ministerie van Verkeer en Waterstaat, *De bestrijding van de verontreiniging van het oppervlaktewater; Indicatief meerjarenprogramma 1975-1979* (Den Haag: Staatsuitgeverij, 1975).

92 Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer & Ministerie van Landbouw en Visserij, *Derde Nota Waterhuishouding* (Den Haag: SDU, 1989).

93 For the history sewage treatment technology see A.M. Buswell, *The Chemistry of Water and Sewage Treatment* (New York: The Chemical Catalog Company, 1928), American Chemical Society Monograph Series; F.E. Bruce, 'Water Supply and Waste Disposal,' in T.I. Williams (ed.), *A History of Technology (Volume VII)* (Oxford: Oxford University Press, 1978), 1363-1398; A.L. Downing, 'Used-Water Treatment Today and Tomorrow,' in C.R. Curds & H.A. Hawkes (eds.), *Ecological aspects of Used-water treatment, Volume 2 Biological Activities and Treatment Processes* (London etc.: Academic Press, 1983), 1-10; P.G. Fohr, *Van wilde bevloeiing tot moderne afvalwaterzuivering* (Wageningen: Veenman & Zonen, 1966), Rede uitgesproken bij de aanvaarding van het ambt van buitengewoon hoogleraar in de waterzuivering aan de Landbouwhogeschool te Wageningen op 23 juni 1966; P.L. Gainey & Th.L. Lord, *Microbiology of Water and Sewage* (Second printing 1956) (London: Longmans, Green & Co, 1952), 315-378; Groenewegen, *Op. cit.*; J.J. Hopmans, 'Geschiedenis van de verwijdering van vloeibare afvalstoffen,' *Land + Water*, June 1959, 100-105; J.J. Hopmans, 'Geschiedenis van de verwijdering van vloeibare afvalstoffen (2),' *Land + Water*, August 1959, 144-153; P.G. Fohr, *Van wilde bevloeiing tot moderne afvalwaterzuivering* (Wageningen: Veenman & Zonen, 1966), Rede uitgesproken bij de aanvaarding van het ambt van buitengewoon hoogleraar in de waterzuivering aan de Landbouwhogeschool te Wageningen op 23 juni 1966; Van Zon, *Op. cit.*. See also *De Ingenieur*, 39(1927)20, 430-445; Water: 50(1966)23, 365-367 and 41(1957)24, 327-331; *H_2O*, 3(1970)22, 551-560; 16(1983)19, 425-432 and 22(1989)13, 398-399.

94 To a certain extent rivers are capable of purifying waste water. The bacteria and other micro-organisms in the water use the organic waste and some other components in the sewage as food. However, the so-called 'self-purifying capacity' of rivers is limited. If too much organic waste is supplied, the bacteria face a shortage of oxygen, and the ecological balances between the different organisms in the water are destroyed.
The 'self-purifying capacity' of a river is dependent on local circumstances like the volume of water carried away by the river and the temperature of the river. This meant that in countries like England, where the rivers are in general smaller than in the Netherlands and were large-scale urbanization and industrialization started earlier, the need for sewage treatment was felt somewhat earlier. Also at places, where there was no or little surface water to discharge to, like in some of the eastern parts of the Netherlands, the need for sewage treatment was felt earlier than at places where there was an 'abundance' of rivers or where the sewage could be pumped to the sea.

95 On the early Dutch sewage treatment installations see Groeneveld, *Op. cit.*; P. Nauta, *Zuivering van afvalwater; Methoden en installaties voor de zuivering van rioolwater en industrieel afvalwater* (met een inleiding van Prof.dr. Jan Smit) (Amsterdam: Ahrend & Zoon, 1937), 141-166; J. Smit, *De hedendaagsche stand van het vraagstuk der zuivering van huishoudelijk en industriëel afvalwater* (Rotterdam: Nijgh & Van Ditmar's Uitgeverij-Maatschappij, 1925), 139-144, Van Zon, *Op. cit.*, *Ingenieur* 29(1914)46, 899-904; 44(1929)13, 119-120 and 52(1936)40, G57-G60. In 1904, a State Test Installation was built in Tilburg to investigate the possibilities of biological treatment of the waste water of the textile industry. In 1912, the installation was closed. The first Dutch sewage treatment plant that employed a trickling filter went in operation in 1906 in *Voorburg,* but closed in 1923 due to the high costs and the lack of required expertise. Henceforth, the waste water was pumped to the sea through a pipe line.

96 See e.g. *Ingenieur*: 18(1913)36, 736-761; 39(1924)16, 285-295 and 42(1927)20, 430-445.

97 On (the history of) the Pasveer Ditch and Carrousel see *De Ingenieur*, 69(1957)17; *H_2O*: 3(1970)22, 551-560; 7(1974)23, 521-523; 16(1983)19, 425-432 and 17(1984)19, 426-430; A. Pasveer, *Eenvoudige afvalwaterzuivering* (rapport no. 26) (Den Haag: Instituut voor Gezondheidstechniek TNO, 1958); *DHV Water Nieuws*, Special 25 jaar Carrousel.

98 For more details, see Chapter 7.

99 Rijksinstituut voor de Zuivering van Afvalwater, *Op. cit.*. *De Ingenieur*, 63(1951)12, G29-G31; *H_2O*, 13(1980)8, 158-161.

100 *Water*, 48(1964)6, 78-79; 46(1962), 338; *H_2O*, 7(1974)19, 397-397; 8(1975)1, 2-5; 10(1977)24, 541-545+551; 11(1978)11, 226-229; 13(1980)8, 161-165. 7(1984)20, 452-456; 18(1985)16, 340-342.

101 Interview Kruit, 15 September 1995; interview Rensink, 10 January 1995.

102 *Ibid.*.

103 Water Board *De Dommel* and Amsterdam initially set up their own Technological Division to design sewage treatment plants. Other Water Boards, like *Regge and Dinkel*, decided not to set up a complete Technological Division because they considered it better to put out work that had to happen only at times. Nevertheless also these boards came to employ some professionals in sewage treatment. In the course of time, some boards have followed the line of reasoning, whereas others have not; the latter are, in some cases, designing complete installations largely by themselves.

104 Lintsen (1985).

105 *Driemaandelijks Bericht Deltawerken*, (1978)83, 115-124.

106 J. van Veen, *Dredge, Drain, Reclaim; The Art of a Nation* (The Hague: Martinus Nijhoff, 1962); D.M. Ligtermoet & H. de Visch Eybergen, *Uitvoering en uitbesteding. Ontwikkelingen in de organisatie van waterbouwkundige werken bij Rijkswaterstaat* (Den Haag: Rijkswaterstaat, 1990), H.A.M.C. Dibbits, *Nederland-waterland; Een historisch-technisch overzicht* (Utrecht: Oosthoek, 1950); H.A. Ferguson, *Delta-visie; Een terugblik op 40 jaar natte waterbouw in Zuidwest-Nederland* (Den Haag: Rijkswaterstaat, 1988); Tj. de Haan, ‘De betekenis van het Deltaplan voor de beveiliging van Nederland tegen het water,’ *Driemaandelijks Bericht Deltawerken*, (1988)123/124, 677-694.

107 Ligtermoet & De Visch Eybergen, *Op. cit.*, 55; Van Veen, *Op. cit.*, 127-128, 135-136.

108 J. van den Ende & M.L. ten Horn-van Nispen, ‘Een natuurkundige in waterland,’ in M.L. ten Horn-van Nispen, M.L. Lintsen & A.J. Veenendaal (eds.), *Wonderen der techniek; Nederlandse ingenieurs en hun kunstwerken 200 jaar civiele techniek* (Stichting Historie der Techniek) (Zutphen: Walburg, 1994), 139-151.

109 *Ibid.*.

110 *Ibid.*; Dibbits, *Op. cit.*.

111 *Ibid.*.

112 *Cf.* Ferguson, *Op. cit.*; Van Veen, *Op. cit.*.

113 Van Veen, *Op. cit.*, 134.

114 Ferguson, *Op. cit.*, 44.

115 Ferguson, *Op. cit.*; Van Veen, *Op. cit*; Ligtermoet & De Visch Eybergen, *Op. cit.*; W. Bijker & E. Aibar, ‘Dutch, Dikes and Democracy; an Argument against Democratic, Flexible, Good and Bad Technologies,’ *Technology & Democracy; The Use and Impact of Technology Assessment in Europe, the 3rd European Congress on Technology Assessment, Copenhagen, 4-7 November 1992* (1992), 538-557; E.K. Duursma, H. Engel & Th.J.M. Martens, *De Nederlandse Delta; Een compromis tussen milieu en techniek in de strijd tegen het water* (2e gewijzigde druk, maart 1983) (Koninklijke Nederlandse Academie van Wetenschappen, 1982); H. Haan & I. Haagsma, *De Deltawerken; Techniek, politiek, achtergronden* (Delft: Waltman, 1984); A.F. Leemans & K. Geerts, *Doorbraak in het Oosterscheldebeleid* (Muiderberg: Dick Coutinho, 1983); Rijkswaterstaat, *Ontwerpnota stormvloedkering Oosterschelde* (Den Haag: Ministerie van Verkeer en Waterstaat en Rijkswaterstaat, 1991); D.F. Westerheijden, *Schuiven in de Oosterschelde; Besluitvorming rond de Oosterschelde 1973-1976* (Enschede: Universiteit Twente, 1988), Proefschrift.

116 Eight members of parliament voted against the Delta law because of these ‘centralist tendencies’ (De Haan & Haagsma, *Op. cit.*, 60-71).

117 Van Veen, *Op. cit.*, 183-184.

118 For (model) research on the Delta plan, see, for example, Schiereck, G.J. & A.W. Walther (1976), 'Waarneming, model en berekeningen', in Rijkswaterstaat Deltadienst (ed.), *De Delta; Een Alma Mater?; Lessen van 20 Jaar Deltawerken*, 19-26; Spaargaren, F. (1976), 'Waterbouwkunde: een noodzakelijk experiment', in Rijkswaterstaat Deltadienst (ed.), *De Delta; Een Alma Mater?; Lessen van 20 Jaar Deltawerken*, 27-36 and *Driemaandelijks Bericht Deltawerken*, (1972)62, 59-70.

119 Bijker & Aibar, *Op. cit.*, 10. Another model that was built to predict water movements was the so-called Deltar - the Delta tidal analogues calculations machine. This model simulated water movements by using the analogy between electric currents and tidal currents.

120 Ferguson, *Op. cit.*, 52.

121 In 1987 the textbook *The Closure of Tidal Basins* appeared. One of the reasons to write it was to make available for the future the experience gathered in the Delta Project (J.C. Huis in 't Veld, J. Stuip, A.W. Walther, *et al.* (eds.), *The Closure of Tidal Basins; Closing of Estuaries, Tidal Inlets and Dike Breaches* (Delft: Delft University Press, 1987)).

122 On the use of the probabilistic approach in the design of the *Oosterschelde* storm surge barrier see Rijkswaterstaat, *Ontwerpnota stormvloedkering Oosterschelde* (Den Haag: Ministerie van Verkeer en Waterstaat en Rijkswaterstaat, 1991); *Driemaandelijks Bericht Deltawerken*, 84(1978), 85 (1978), 86(1978) and 87(1979); and Duursma *et al., Op. cit.*, 112-113. On the use of the probabilistic approach in the design of the *Nieuwe Waterweg* storm surge barrier see *Volkskrant*, 18 February 1995; *UT-Nieuws*, 16 March 1995 and P.L. Spits, 'De rol van beton in de stormvloedkering Nieuwe Waterweg,' *Cement*, 45(1993)5, 6-11. The probabilistic approach may also be applied to other aspects besides the strength (chance of failure) of the construction.

123 Ligtermoet & De Visch Eybergen, *Op. cit.*, 55; Spaargaren, *Op. cit.*; Van Veen, *Op. cit.*.

124 Ligtermoet & De Visch Eybergen*, Op. cit.*, 56.

125 *Ibid.*. On the history of Dutch contractors active in the construction of hydraulic works, see Leeuwen, W.R.F. van (1993), 'Waterbouw', in H. Lintsen, *et al.* (ed.), *Geschiedenis van de techniek in Nederland (Deel III)*, Zutphen: Walburg, 233-249.

126 Ligtermoet & De Visch Eybergen*, Op. cit.*.

127 *Ibid.*, 58.

128 *Ibid.*, 21-34 and 62-63.

129 *Ibid.*, 58.

130 Bijker & Aibar, *Op. cit.*, 10; Westerheijden, *Op. cit.*; Ligtermoet & De Visch Eybergen, *Op. cit.*, 47-53 and 62-65; *Driemaandelijks Bericht Deltawerken*, 103(1983), 165-173.

131 Ligtermoet & De Visch Eybergen*, Op. cit.*, 49 and 62-63.

132 This regime description is mainly based on P.I.M. de Kwaadsteniet & H.E. van Capelleveen, *Signaaladvies natuurvriendelijke oevers* (uitgevoerd door TAUW Infra Consult B.V. in opdracht van de Raad voor het Milieu-en Natuuronderzoek) (Rijswijk: RMNO, 1993), Publikatie RMNO nr. 85; Nederlandse Vereniging Kust- en Oeverwerken, *Handboek oeverbeschermingsconstructies* (Rotterdam: K&O, 1983); Nederlandse Vereniging voor Kust- en Oeverwerken, *Kust en oeverwerken; In praktijk en theorie* (Rotterdam: Nederlandse Vereniging voor Kust- en Oeverwerken, 1980); Ministerie van Verkeer en Waterstaat en Rijkswaterstaat, *Meerjarenplan Oevers; Achtergronden* (Delft: Dienst Weg- en Waterbouwkunde, 1989), In opdracht van de dienst Weg- en Waterbouwkunde uitgevoerd door Ingenieursbureau 'Oranjewoud' bv.; Rijkswaterstaat, *Oeveronderzoek bij de Dienst Weg- en Waterbouwkunde; vijfjarenplan ('90-'94)* (Delft: Dienst Weg- en Waterbouwkunde, 1990); interview Boeters and Boks, interview Markerink, 30-11-1994, interview Nieboer, 5-12-1994; interview Paans 14-11-1994; interview Van Selm, 15-12-1994.

133 Contractors may, for example, influence the choice of materials by offering certain cheap materials. In such cases, it is often financially attractive for the bank administrator to let influence his materials choice by the contractor. Locally, there may exist strong ties among bank administrators and certain contractors. For administrators it is sometimes attractive to choose the same contractor every time because that contractor knows the area and the wishes of the administrator well and because the administrator knows what to expect from the

contractor. Private tenders will be regular in such cases and it is probable that bank design is influenced by the constructions and materials available at the contractor. This is especially true for smaller projects. For larger projects, it is legally obligatory to put up work to public tender (interview Boeters and Boks, interview Markerink, 30-11-1994, interview Paans 14-11-1994).

134 Interview Markerink, 30-11-1994.

135 *Ibid.*.

136 Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer & Ministerie van Landbouw en Visserij, *Derde Nota Waterhuishouding* (Den Haag: SDU, 1989).

137 Nederlandse Vereniging Kust- en Oeverwerken, *Op. cit. 1980 and 1983*.

138 Nederlandse Vereniging Kust- en Oeverwerken, *Op. cit. 1983*.

139 Other reasons for developing new construction and working techniques were a relative scarcity of labor and of some of the traditionally used construction materials (Nederlandse Vereniging Kust- en Oeverwerken, *Op. cit. 1983*, 7).

140 Nederlandse Vereniging Kust- en Oeverwerken, *Op. cit., 1983*, interview Boeters & Baks.

141 Interview Boeters & Baks.

142 Nederlandse Vereniging Kust- en Oeverwerken, *Op. cit., 1980* and *1983*.

143 *Cf.* D.M. Ligtermoet & H. de Visch Eybergen, *Uitvoering en uitbesteding. Ontwikkelingen in de organisatie van waterbouwkundige werken bij Rijkswaterstaat* (Den Haag: Rijkswaterstaat, 1990).

144The *Nederlandse Vereniging Kust- en Oeverwerken* organizes about forty firms of contractors, accounting to about 90-95 % of the total number of contractors in this sector, at least according to themselves. It was erected in 1954 and serves a number of functions. It acts like representative, intermediary and agent to the government, research institutes and educational institutes. The other association of contractors that is relevant for bank design is the *Vereniging Aannemersbond in Weg- en Waterbouw*.

145 Interview Boeters & Baks.

146 Ministerie van Verkeer en Waterstaat en Rijkswaterstaat, *Meerjarenplan Oevers; Actergronden* (Delft: Dienst Weg- en Waterbouwkunde, 1989), In opdracht van de dienst Weg- en Waterbouwkunde uitgevoerd door Ingenieursbureau 'Oranjewoud' bv..

147 Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer & Ministerie van Landbouw en Visserij, *Derde Nota Waterhuishouding* (Den Haag: SDU, 1989).

148 The regime description is mainly based on P.W. Brooks, 'Aircraft and Their Operation,' in T.I. Williams (ed.), *A History of Technology (Volume VII)* (Oxford: Oxford University Press, 1978), 789-836; L. Bryant, 'The Internal Combustion Engine,' in T.I. Williams (ed.), *A History of Technology (Volume VII)* (Oxford: Oxford University Press, 1978), 997-1024; K. Hayward, *International Cooperation in Civil Aerospace* (London: Pinter, 1986), 125-156; K. Hayward, *The British Aircraft Industry* (Manchester & New York: Manchester University Press, 1989); R. Miller & D. Sawers, *The Technical Development of Modern Aviation* (London: Routledge & Kegan Paul, 1968); G.R. Simonson (ed.), *History of the American Aircraft Industry: An Anthology* (Cambridge (ma.): MIT, 1968); D. Todd & J. Simpson, *The World Aircraft Industry* (Dover (Ma.): Croom Helm, 1986); *Astronautics & Aeronautics* 1975-1992; *Interavia Aerospace Review* 1990-1993.

149 Hayward, *Op. cit. 1986*; *Interavia Aerospace Review*: January 1990, 28-35; November 1991, 53-65; February 1991, 11-16 and 22-23; November 1992, 16-18. (Firms from the (former) Soviet Union are not taken into consideration.
In the sixties and seventies, the American firm P&W was by far the largest producer of civil aero-engines. In 1966, P&W had a market share of more than 90% of the civil aero-engine market. Since 1984, P&W's market share, however, has declined from more than 60% to less than 30%. By now, GE is the world's single largest producer of civil aero-engines.

150 *Interavia Aerospace Review*: February 1991, 11-16 and 22-23; November 1991, 53-65 and 72-74; December 1991, 38-42 January 1992, 33-37; November 1992, 16-18.

151 According to Todd & Simpson (*Op. cit.*, 145 ff) describing the Phillips Eclectic Model) the dominance of a small number of large companies in aircraft (and aero-engine) design is the *result* of technological developments, not the cause. Smaller companies have not been able to catch up with the rate of innovations and the required large development costs.

152 *Astronautics & Aeronautics*, July/August 1977, 48-53; Hayward, *Op. cit. 1986*, 17-18 and Millers & Sawers, *Op. cit.*, 266-277.

153 Hayward, *Op. cit. 1989*; Todd & Simpson, *Op. cit.*; Miller & Sawers, *Op. cit.*, 277-281. Immediately after the Second World War, there were still a large number of aero-engine companies, especially in a country like England. Most of the smaller companies have not been able to survive independently. Main reasons are the rising development costs for new engines and the consequently growing commercial risks. In Europe, the situation was further aggravated by the lack of a large home market. Civil aviation is to a great measure an American business and American firms are leading in both aero-engine and aircraft production. The European answer to the American hegemony and the deteriorating prospects of small (European) companies have been governmentally induced mergers, nationalization (especially in France) and international cooperation.

154 Rolls Royce even went (temporarily) bankrupt in 1971 due to the high costs of developing independently a high-bypass turbofan, combined with a too optimistic contract with Lockheed. Rolls Royce was subsequently nationalized by the British government, to become a private company again in 1987 (Hayward, *Op. cit. 1989*, 134-140, 158-165).

155 *Interavia Aerospace Review*: January 1990, 28-35 estimates the costs at 1.5 - 2 billion dollar.

156 Hayward, *Op. cit. 1986*; *Interavia Aerospace Review*: January 1990, 28-35; February 1991, 11-16 and 22-23; November 1991, 53-65; May 1991, 50-52; 72-74; January 1992, 33-37; *Flight International*, 145(1994)4424, 33-40
A first type of commercial construction consists in the three larger aero-engine companies (P&W, GE and R.-R.) seeking smaller revenue or risks-sharing partners for the development and production of particular aero-engines.
A second type of construction is the formation of formal alliances among aero-engine companies for co-production and co-design of (particular) aero-engines. A number of such civil alliances now exist. They include CFM International (GE/Snecma); International Aero-engines (Rolls Royce, P&W, JAE, Fiat and MTU); CFE (Allied Signal/GE); Williams Royce (RR/Williams); BMW Rolls Royce (RR/BMW) and United Technologies/Daimler Benz (P&W/MTU).
Some of these alliances are product-based, others applies to a family of engines. The latter is especially true of CFM, the alliance between GE and Snecma; both firms that originally mainly were active in the military sector. This alliance was set up in 1971 and has successfully developed a family of civil aero-engines. GE also develops large aero-engine outside the alliance. In such cases, however, Snecma often is an important risk-sharing partner. (Snecma has a 25% stake in the GE90, GE's newest engine).

157 Hayward, *Op. cit. 1986 and 1989*; Todd & Simpson, *Op. cit.*.

158 In Europe, governments have also been deeply involved in restructuring the national aero-engine and aircraft industries through mergers, nationalization and international cooperation as to restore economic profitability and long-term viability.

159 Hayward, *Op. cit. 1986*, 125.

160 Nevertheless, the aircraft manufacturer may selects a launch engine for its new models. If this happens, the new engine has a competitive advantage over other types of engines.

161 An important development in this respect is the tendency to design aircraft for two instead of three or four engines. This requires engines with a higher thrust, not only because less aero-engines are to drive the aircraft, but also because safety rules require that aircraft can fly with one failing engine. This means that aero-engines for twin aircraft have to have a maximum thrust of twice the thrust needed to get off the ground; for engines with three or four engines the extra required thrust is less. (M.J.T. Smith, *Aircraft Noise* (Cambridge Aerospace Series) (Cambridge etc.: Cambridge University Press, 1989); *Interavia Aerospace Review*, February 1991, 18-20).

162 Hayward, *Op. cit. 1986 and 1989*; Todd & Simpson, *Op. cit.* and Miller & Sawers, *Op. cit.*.

163 American companies like Boeing and McDonnell Douglas dominate the market for larger long-distance planes, although - as a 'reaction' to American hegemony and rising developments costs - the European consortium Airbus have been successfully set up, now being one of the main producers of large aircraft.

164 *Cf.* Smith, *Op. cit.*.

165 F.A. Spencer, *Transport Jet Aircraft Noise Abatement in Foreign Countries; Growth, Structure, Impact* (Final Report, Vol. 1-2) (1980), Report for NASA Ames Research Center.

166 *Astronautics & Aeronautics*, May 1978, 40-47.

167 *Ibid.*, 42. Typical design criteria in aicraft design are performance, the seize/weight ratio, costs, environmental effects, avialable resources, safety, survivability, comfort, handling/flying qualities. For each specific design, a Measure Of Merit (MOM) may be formulated, depending on specific user needs and wishes (*Astronautics & Aeronautics*, June 1979, 22-31).

168 For the idea of different major phases in airplane (and aero-engine) design see Miller & Sawers, *Op. cit.*, 257-263; Todd & Simpson, *Op. cit.*, 150 and Nelson & Winter (1977, 1982). Both Todd & Simpson and Nelson & Winter base their evidence on Miller & Sawers.

169 Given are the dates when the new technologies are *applied* at a serious scale to aircraft and aero-engine design. This is evidently not the same date as the invention. The first three phases are based on Miller & Sawers (*Op. cit.*, 257-263). They give the following dates 1908-1912, 1930-1933, 1942-1947. I have defined the phases somewhat broader and changed the dates of the final period because the dates given by Miller & Sawers also relate to the application in military design. The turbojet was first used for military purposes and only later applied to civil aviation, as we saw before. For the (third and) fourth phase see, for example, Smith, *Op. cit.*.

170 Based on suggestion from Hans Heerkens. The alignment of new designs with new functions becomes evident if one looks at the developments in commercial aviation. The first period was connected with the function 'flight.' In the thirties, reliable flight became possible. This period witnessed the real birth of commercial (passenger) flight. The introduction of the jet in the fifties made long-distance high-altitude flight possible. Now intercontinental flight became possible in an efficient way. Especially the large jets turned out to be a very efficient means of propulsion, in terms of direct operating costs. This also led to a rapid expansion of airline business. Finally, the introduction of wide body aircraft with high bypass engines was related to the function 'high capacity aircraft with lower fuel consumption.' Both (high capacity, lower fuel consumption) made flight cheaper. It took some time before the demand of this function was established. Boeing, which was the first to introduce a wide-body aircraft with high-bypass engines, the Boeing 747, was almost bankrupted by high development costs and low initial sales. Nevertheless, wide body aircraft was eventually successful.

171 Millers & Sawers, *Op. cit.*, 257-263.

172 *Ibid.*, 246; Todd & Simpson, *Op. cit.*, 145-153.

173 Tushman & Anderson (1986); Constant (1980).

174 Constant (1980). See also Chapter 2.

175 Todd & Simpson, *Op. cit.*, 245ff; Tushman & Anderson (1986); Constant (1980).

176 Research is also done at universities. Their role in research is, however, relatively small. Universities play a more important role with respect to education.

177 Innovations in military aviation may also originate in civil aviation. According to Miller & Sawers (*Op. cit.*, 257-263), many important innovations originated in civil aviation.

178 In many publications on the aero-engine and aircraft industry, the idea can be found that preparedness to innovate, commitment to R&D and the ability to invest huge development costs are as crucial ingredients for survival in the aero-engine business. The following quote is - in its extremity - typical: '... what really sets the commercial airplane business apart is the enormity of the risks as the well as the costs that must be accepted; they create an array of obstacles to profitability, hence viability, which discourages all but the bold and committed ...' (J. Newhouse, *The Sporty Game* (New York: 1981), 3; cited in Hayward, *Op. cit. 1986,*1). If this idea indeed holds, is difficult to say. However, as an idea, it may influence the behavior of those involved in the aero-engine industry and possibly lead to a self-fulfilling prophecy.

179 Tushman & Anderson (1986); Constant (1980).

180 Brooks, *Op. cit.*, 829-834; Miller & Sawers, *Op. cit.*, 281-286; Smith, *Op. cit.*; *Astronautics & Aeronautics*, January 1977, 66-75; H. Wittenberg, *De ontwikkeling van vliegtuigen met snelheden groter dan de geluidssnelheid* (Delft: Waltman, 1955), Rede, uitgesproken bij de aanvaarding van het ambt van lector in de vliegtuigbouwkunde aan de Technische Hogeschool te Delft op 2 juni 1955; H. Wittenberg, *Het ontwerpen van vliegtuigen* (Delft: Waltman, 1961), Rede, uitgesproken bij de aanvaarding van het ambt van gewoon hoogleraar in de vliegtuigbouwkunde aan de Technische Hogeschool te Delft op woensdag 15 november 1961; *De Ingenieur*, 85(1973)17, 343-348 and 90(1978)49, 949-952.

181 F.G. Dawson, *Nuclear Power; Development and Management of a Technology* (Seattle and London: University of Washington Press), 1976.

182 Gulf-General Atomic entered the market in 1972. By the end of that year, it had acquired orders for seven High Temperature Gas-cooled Reactors (HTGRs). In 1974, however, all of Gulf's order except for two were canceled (Dawson, *Op. cit.*, 140-143).

183 C.W. Forsberg, L.J. Hill, W.J. Reich, *et al.*, *the Changing Structure of the International Commercial Power Industry* (Oak Ridge National Laboratory, 1992).

184 L. Scheinmann, *The International Atomic Energy Agency and World Nuclear Order* (Washington: Resources for the Future, 1987).

185 The description of the early efforts to develop reactors in the USA in mainly based on J.M. Jasper, *Nuclear Politics; Energy and the State in the United States, Sweden, and France* (Princeton: Princeton University Press, 1990) and G.T. Mazuzan & J.S. Walker, *Controlling the Atom; The Beginnings of Nuclear Regulation 1946-1962* (Berkeley etc.: University of California Press, 1984). For the submarine project see also S. Frickel, 'Engineering Heterogeneous Accounts: The Case of Submarine Thermal Reactor Mark-I', *Science, Technology & Human Values*, 21(1996)1, 28-53.

186 W.A. Smit, 'Over kernwapens; Het nonproliferatiestreven door de jaren heen,' *Transaktie*, 10(1981)1, 5-58. In 1946, negotiations between the United States and the Soviet Union about a proposal to internationalize atomic energy failed. The Americans, therefore, stuck to the 1946 Act.

187 Private industry was allowed a role in the project as far as was possible within the framework of 1946 bill. In fact, since the late forties, private companies, like Monsanto, Dow Chemical and the Detroit Edison Company, had been pressing the AEC to let them develop nuclear reactors. In 1951, the AEC established its Industrial Participation Program offering a number of firms the possibility to study reactor designs.

188 Shippingporte was not the first civilian nuclear power plant world-wide. This honor went in 1954 to the USSR. (H. van Dam, 'On the History of Nuclear Energy' (1992), Presentation at the International Conference on the Fiftieth Anniversary of the Fermi Reactor and on Peaceful Applications of Nuclear Energy, 14-16 October 1992, Liege, Belgium). The fear that the Soviets would take the lead in the development of peaceful applications in atomic energy was one of the motives in the USA to enhance the development of power reactors.

189 Mazuzan & Walker, *Op. cit.*, 22.

190 Smit, *Op. cit.*, 8-9.

191 GE concentrated its efforts on the Boiling Water Reactor (BWR), Westinghouse on the Pressurized Water Reactor (PWR).

192 The history of the development of nuclear reactors outside the USA is mainly based on Bupp, I.C. & J.-C. Derian (1978), *Light Water; How the Nuclear Dream Dissolved*, New York: Basic Books; Jasper, *Op. cit.*; and H.R. Nau, *National Politics and International Technology; Nuclear Reactor Development in Western Europe* (Baltimore and London: The Johns Hopkins University Press, 1974).
In most countries outside the USA initial development efforts did not concentrate on the LWR. This had two main reasons. First, LWRs need enriched uranium as fuel. Since the 1946 US Atomic Energy Act prohibited the export of (enriched) uranium and of technology and know-how to enrich uranium, most countries were 'forced' to develop reactors using natural uranium. Canada and Sweden, for example, concentrated their efforts on the heavy water reactor (HWR). In Canada these efforts had a strictly civilian character. In Sweden, however, early

attempts had (secret) military goals.
Second, some countries used the development of (civilian) nuclear reactors as a means to produce plutonium for an atomic bomb. Britain, for example, concentrated its efforts on gas-cooled graphite-moderated reactors, which effectively produced plutonium. After 1952, also France concentrated its efforts on this type of reactor. Until 1952, French efforts mainly had a scientific character and concentrated on heavy water (test) reactors. After 1952, however, these efforts more and more got a military and commercial character and the country switched to gas-graphite reactors.

193 The EURATOM-US Joint Agreement and its consequences for the prospects of the LWR in Europe are in detail described in Nau, *Op. cit.*, Chapter 5.

194 France did not offer its technology because it wanted EURATOM to be complementary to its own program instead of a substitution of it. The UK was not member of EURATOM because it opposed supranational unity in Europe. Besides, the UK would probably not have been able to offer technology on the same terms as the Americans did. Germany had leaned on the USA for the development of nuclear reactor technology since 1955, when the ban on reactor development for peaceful applications in Germany was released by the Allied Forces (Nau*, Op. cit.,* 73-74). Forestalling international suspicion had been a mean reason for Germany to rely on the Americans: the USA were the largest ally and had always stressed the *civil* use of nuclear power.

195 The Joint Agreement reactor and research program had little impact on actual reactor development and construction in Europe. Nevertheless, it created the impression that the LWR was technologically at least at equal footing with the gas-graphite reactors (Nau, *Op. cit.*).

196 In 1958, the design competition for Italy's first nuclear reactor was won by GE, which had just left behind a number of British firms that offered gas-graphite reactors. In 1962, the design competition for an important German plant was won by GE/AEG with as main competitor English Electric/Siemens, which offered a gas-graphite plant. As a result, Siemens switched priorities to nuclear reactors using enriched uranium as fuel.

197 J.H. de Boer, *Het wetenschappelijk onderzoek op het gebied van de kernenergie* (Groningen: Wolters, 1963), Rede uitgesproken op 13 december 1962 ter gelegenheid van de opening van het natuurkundig laboratorium van de rijksuniversiteit te Groningen, 13.

198 *Ibid.*, Jasper, *Op. cit.*.

199 The policy of the AEC in these days was based on the premise 'that the government should restrict its activities to exploring advanced reactor concepts on a pilot scale by building small experimental reactors.' (Bupp & Derian, *Op. cit.*, 34). The Joint Committee on Atomic Energy (JCAE) of the American House and Senate, which was dominated by Democrats, argued for a more active role of the government in the development of nuclear technology, but they were not very successful in this respect.

200 The Price-Anderson Act was the 'result' of a report the AEC published in 1957 on the risks of nuclear energy. In this Brookhaven report, also called WASH-740, a worst-case scenario was described of a nuclear plant accident in which 3000 people would die immediately, more than 40,000 people would be seriously injured and the property damage would be 7 billion dollars. The effect of the report was to scare off insurance companies. As a response, the American government issued the Price-Anderson Act. In the course of time, similar regulations have been agreed upon in most European countries.

201 Cited in Bupp & Derian, *Op. cit.*, 45.

202 This Swedish decision was clearly influenced by the Oyster Creek deal (A. Kaijser, 'Redirecting Power; Swedish Nuclear Power Politics in Historical Perspective,' *Annu. Rev. Energy Environ.*, 17 (1992), 437-462).

203 France tried to export gas-graphite technology and to make this technology a basis for further EURATOM cooperation. However, with little success (Nau, *Op. cit.*, Chapter 3 and 5). The decision to switch to LWR technology was taken after a lasting struggle between the government owned utility EDF (Electricité de France) promoting LWR technology and the governmental CEA (Commissariat à l'Energie Atomique) promoting the gas-graphite line. EDF promoted the LWR not only because it thought it to be more cost-effective, but also the gain more control over the development of nuclear power in France at the expensive of the CEA.

204 Bupp & Derian, *Op. cit.*, 50-55.

205 Bupp & Derian, *Op. cit.*, 179-185.

Samenvatting

Centraal in dit proefschrift staat de transformatie van technologische regimes. Technologische regimes zijn gedefinieerd als het geheel van regels die een rol spelen bij het ontwerp en de verdere ontwikkeling van een techniek. Dergelijke regels worden geïmpliceerd door bijvoorbeeld gedeelde ontwerpcriteria, technische modellen en beloftes en verwachtingen. Technologische regimes worden gekenmerkt door sociale en technische sluiting. Sociale sluiting legt beperkingen op aan wie op welke wijze aan het ontwerp en de verdere ontwikkeling van een techniek kan bijdragen. Technische sluiting betekent dat er beperkingen bestaan met betrekking tot de ontwikkeling van nieuwe technieken. Bepaalde technische opties kunnen gemakkelijker ontwikkeld worden dan andere. Tijdens de transformatie van een technologisch regime worden de bestaande sociale en technische sluiting (tijdelijk) opgeheven.

Om te begrijpen hoe en in welke omstandigheden transformatie van technologische regimes optreedt, wordt in hoofdstuk 1 de sociologische theorie van Boudon geïntroduceerd en toegepast op techniekontwikkeling. Op basis van deze theorie worden drie typen processen van techniekontwikkeling onderscheiden: reproductieprocessen, processen van cumulatieve innovatie en transformatieprocessen. In het geval van reproductieprocessen is er sprake van een stabiel, niet veranderend technisch ontwerp. In het geval van processen van cumulatieve innovatie is er sprake van een stabiel patroon van techniekontwikkeling. In het geval van transformatieprocessen kan transformatie van het bestaande regime optreden.

Transformatieprocessen komen op gang wanneer terugkoppelingen uit de omgeving van het regime manifest worden, bijvoorbeeld wanneer derden klagen over de (onbedoelde) negatieve bijeffecten van een techniek. In het algemeen worden transformatieprocessen op gang gebracht door buitenstaanders. In dit proefschrift zijn buitenstaanders gedefinieerd als mensen die de regels van het bestaande regime niet delen.

Op basis van de theorie van Boudon worden twee specifieke mechanismen onderscheiden die een rol spelen bij het in gang zetten van transformatieprocessen: agressie en beroep. In het geval van agressie produceert het bestaande technologische regime (bij-)effecten die niet gewaardeerd worden in de omgeving van het regime. Buitenstaanders kunnen hun stem verheffen tegen die effecten en proberen deze terug te koppelen naar het bestaande regime. In het geval van beroep wordt het regime gekenmerkt door bepaalde interne spanningen of problemen die manifest gemaakt worden door buitenstaanders. Een typisch voorbeeld is een beroep op buitenstaanders die kennis bezitten die van nut is voor het ontwerp van een techniek.

Verder wordt betoogd dat de transformatie van technologische regimes moet worden bestudeerd als een samenspel tussen het individuele of actorniveau en het structurele niveau. In dit geval zijn de belangrijkste structuren zogenaamde ‘innovatiepatronen’. Deze patronen zijn een weerslag van de afhankelijkheden en rolrelaties die tussen actoren in een technologisch regime bestaan. Ze impliceren verschillen in de wijze waarop technische innovatie tot stand komt in een technologisch regime. Vier innovatiepatronen worden onderscheiden: het toeleverancierafhankelijke innovatiepatroon, het gebruikergedreven innovatiepatroon, het missiegeoriënteerde innovatiepatroon en het R&D-afhankelijke innovatiepatroon. In het toeleverancier-afhankelijke innovatiepatroon worden innovaties geïnitieerd door toeleveranciers van onderdelen of grondstoffen. In het gebruikergedreven innovatiepatroon komen innovaties tot stand in reactie op (nieuwe) functionele vereisten van gebruikers. In het missiegeoriënteerde innovatiepatroon komen innovaties tot stand op grond van missies geformuleerd door een beperkt aantal actoren die als opdrachtgever en gebruiker van de betreffende techniek fungeren. Het gaat daarbij vaak om de overheid als opdrachtgever en gebruiker. In het R&D-afhankelijke innovatiepatroon starten innovaties met nieuwe technische en wetenschappelijke ideeën.

De eerste onderzoeksvraag luidt hoe deze vier innovatiepatronen transformatieprocessen mogelijk maken en beperken, en in welke opzichten ze hierin van elkaar verschillen. Deze onderzoeksvraag wordt beantwoord door het uitvoeren van een meervoudige casestudie. Daartoe zijn bij elk innovatiepatroon twee cases geselecteerd, zodat in totaal acht cases bestudeerd zijn. De volgende cases werden onderzocht: huishoudkoelkasten en verf (toeleverancierafhankelijke innovatiepatroon), kippenhuisvestingssystemen en rioolwaterzuiveringsinstallaties (gebruikergedreven innovatiepatroon), zeekeringen en oevers (missiegeoriënteerde innovatiepatroon) en vliegtuigmotoren en kernreactoren (R&D-afhankelijke innovatiepatroon).
In aanvulling op de eerste onderzoeksvraag is een tweede geformuleerd over de mechanismen die een rol spelen bij de transformatie van technologische regimes. Deze vraag wordt beantwoord op basis van een uitgebreide beschrijving van de verschillende cases en een vergelijking van empirisch waargenomen mechanismen met het conceptuele kader en relevante literatuur.

In hoofdstuk 2 wordt een aantal conceptuele hulpmiddelen behandeld voor de analyse van technologische regimes en transformatieprocessen. Er wordt aandacht besteed aan de verschillende (actor-)rollen in technologische regimes en aan mechanismen van techniekontwikkeling. Ook worden de vier innovatiepatronen onderscheiden op basis van een empirische studie van Pavitt die beschrijft hoe verschillende typen bedrijven op verschillende wijzen innovaties tot stand brengen. Dit onderscheid wordt verder uitgediept door het in het verband te brengen met het algemene conceptuele kader dat ontwikkeld is in hoofdstuk 1.

In hoofdstuk 3 wordt aangegeven hoe de cases geselecteerd zijn en hoe de verzameling van data heeft plaatsgevonden. In dit hoofdstuk wordt ook getoond dat de geselecteerde cases representatief zijn voor het innovatiepatroon waarvoor ze werden geselecteerd.

De transformatieprocessen met betrekking tot de technologische regimes van verf en koelkasten (toeleverancierafhankelijk innovatiepatroon) worden besproken in hoofdstuk 4. In beide gevallen trad transformatie van het bestaande regime op in de

zin dat duurzaamheid een belangrijker ontwerpcriterium werd. Beide transformatieprocessen werden in gang gezet door milieugroepen en kritische wetenschappers — buitenstaanders met betrekking tot het bestaande regime. Zij slaagden er in om negatieve milieueffecten van het bestaande regime manifest te maken zodat bepaalde andere groepen die meer direct invloed konden uitoefenen op de gang van zaken in het regime, zoals overheden en gebruikers, pogingen gingen ondernemen het bestaande regime te veranderen.
De transformatieprocessen werden op verschillende manieren mogelijk gemaakt en beperkt door het bestaande toeleverancierafhankelijke innovatiepatroon. Doordat toeleveranciers pro-actief — voordat het streven naar duurzaamheid een issue werd in het gehele regime — bepaalde technische alternatieven ontwikkelden, creëerden zij nieuwe handelingsopties voor andere actoren. Hiermee werd met name voor de overheid de mogelijkheid geschapen om in te grijpen in het bestaande regime en een transformatie richting duurzaamheid als ontwerpcriterium te bevorderen. De aanwezigheid van technische alternatieven gaf daarnaast gebruikers de mogelijkheid om voor een nieuwe technische optie te kiezen en zo, bedoeld of niet, het bestaande regime te transformeren.
Behalve mogelijkheden scheppend werkte het toeleverancierafhankelijke innovatiepatroon ook beperkend. Technische alternatieven die niet pasten bij de belangen of R&D-capaciteiten van toeleveranciers konden moeilijker of niet ontwikkeld worden. Ook niet als deze alternatieven potentieel grote milieuvoordelen opleverden en dus pasten binnen het streven naar duurzaamheid als ontwerpcriterium.

De transformatieprocessen met betrekking tot de technologische regimes kippenhuisvestingssystemen en rioolwaterzuiveringsinstallaties (gebruikergedreven innovatiepatroon) worden beschreven in hoofdstuk 5. Deze cases verschillen in de wijze waarop de bestudeerde transformatieprocessen in gang gezet werden. In het geval van kippenhuisvestingssystemen protesteerden dierenbeschermingsgroepen tegen de aantasting van dierenwelzijn in bestaande kippenhuisvestingssystemen. Het transformatieproces kwam dus op gang in reactie op de agressie van het bestaande regime. In het geval van rioolwaterzuiveringsinstallaties probeerden microbiologen en later biotechnologen een belangrijkere rol te verwerven in het ontwerp van deze installaties. Hier ging het om een beroep op de omgeving.
Het gebruikersgedreven innovatiepatroon bleek zowel mogelijkheden scheppend als ook beperkend voor transformatieprocessen. Het is mogelijkheden scheppend omdat terugkoppelingen uit de omgeving op verschillende wijzen kunnen resulteren in nieuwe functionele vereisten van gebruikers en zo in transformatie van het bestaande regime. Het is beperkend omdat gebruikers vaak een korte termijn perspectief hebben en daarom niet de pro-actieve ontwikkeling van technische alternatieven in gang zetten. In de bestudeerde cases betekende dit dat technische alternatieven in ’beschermde ruimtes’ buiten het bestaande regimes ontwikkeld moesten worden.

De transformatieprocessen in de regimes zeekeringen en oevers (missiegeoriënteerd innovatiepatroon) worden beschreven in hoofdstuk 6. In beide gevallen leidde het bestudeerde transformatieproces er toe dat ‘integraal waterbeheer’ onderdeel ging

uitmaken van de missie van het bestaande regime en ging functioneren als nieuw ‘guiding principle’. Bij het tot stand komen van beide transformatieprocessen speelden zowel het mechanisme agressie als het mechanisme beroep een rol. Agressie speelde een rol omdat de bestaande technieken negatieve milieueffecten hadden waar tegen geprotesteerd werd en die vervolgens teruggekoppeld werden naar het bestaande regime. Beroep speelde een rol in de zin dat ecologen en biologen nauwer betrokken raakten in het bestaande regime.
De wijze waarop het missiegeoriënteerde innovatiepatroon transformatieprocessen mogelijk maakt en beperkt bleek vergelijkbaar met de wijze waarop dat in het gebruikergedreven innovatiepatroon gebeurt. In beide gevallen starten innovaties gewoonlijk met de formulering van nieuwe functies. Er zijn echter ook belangrijke verschillen tussen beide innovatiepatronen. Missies worden door een beperkt aantal actoren met een langetermijnperspectief geformuleerd. Zij zullen eerder dan individuele gebruikers pro-actief technische alternatieven (laten) ontwikkelen. Bovendien kunnen zij relatief effectief het regime bewust transformeren via een herformulering van de missie. Anderzijds zijn zij ook in een relatief goede positie om de ontwikkeling van technische alternatieven, en daarmee de transformatie van het bestaande regime, te blokkeren.

De transformatieprocessen in de regimes vliegtuigmotoren en kernreactoren (R&D-afhankelijk innovatiepatroon) worden beschreven in hoofdstuk 7. Ze hadden betrekking op het streven naar inherente veiligheid als nieuwe ontwerpaanpak voor kernreactoren en op het streven naar stillere vliegtuigmotoren. Deze transformatieprocessen werden mogelijk gemaakt door het bestaande R&D-afhankelijke innovatiepatroon omdat dit patroon gekenmerkt wordt door een hoog tempo van technische verandering en door innovatie in elkaar opvolgende generaties. De beoogde transformaties konden deels geïncorporeerd worden in volgende-generatie ontwerpen. Het R&D-afhankelijke innovatiepatroon was ook belemmerd in de zin dat het in beide gevallen resulteerde in een ‘technological fix’ voor een probleem dat gedeeltelijk maatschappelijk van aard was.

In hoofdstuk 8 worden de antwoorden op de onderzoeksvragen besproken en enkele aanvullende conclusies getrokken. Met betrekking tot de eerste onderzoeksvraag wordt geconcludeerd dat verschillende innovatiepatronen inderdaad op verschillende wijzen transformatieprocessen mogelijk maken en beperken. De mate waarin en de wijze waarop de verschillende innovatiepatronen transformatieprocessen mogelijk maken en beperken wordt uitgediept door te kijken naar in hoeverre en hoe de verschillende innovatiepatronen de ontwikkeling van technische alternatieven, die niet geheel in het bestaande regime passen, mogelijk maken en beperken. Het blijkt dan dat het gebruikergedreven innovatiepatroon het meest beperkend is omdat gebruikers vaak een kortetermijnperspectief hebben en niet pro-actief technische alternatieven (laten) ontwikkelen. In de andere drie patronen is wel sprake van de pro-actieve ontwikkeling van technische alternatieven. In het R&D-afhankelijke innovatiepatroon kunnen transformaties bovendien ingepast worden in volgende-generatie ontwerpen. Zodoende schept dit innovatiepatroon meer mogelijkheden voor transformatieprocessen dan de andere drie.

Verder wordt geconstateerd dat innovatiepatronen ook zelf tijdens een transformatieproces kunnen veranderen maar dat dat minder vaak gebeurt dan de transformatie van technologische regimes. Dit komt doordat de regels die kenmerkend zijn voor een technologisch regime gemakkelijker veranderen dan de afhankelijkheids- en rolrelaties tussen actoren die kenmerkend zijn voor een innovatiepatroon.
Met betrekking tot de tweede onderzoeksvraag worden allereerst, op basis van de cases, vier routes onderscheiden voor transformatie van technologische regimes: delegitimatie, regulering, gebruikersdruk en de betrokkenheid van aanvankelijke buitenstaander-professionals in een technologisch regime. De eerste drie routes hangen samen met het mechanisme agressie: ze leiden tot de terugkoppeling van negatief gewaardeerde (bij-)effecten van een techniek naar het bestaande regime. De vierde route hangt samen met het mechanisme beroep. Het onderscheiden van deze vier routes beantwoordt de tweede onderzoeksvraag niet uitputtend. Het succes van deze vier routes, en daarmee van de transformatie van een technologische regime is namelijk afhankelijk van twee onderliggende processen of mechanismen. Ten eerste is het proces van technische agendabouw belangrijk. Dit is het proces waarin de centrale elementen (regels) van een technologisch regime geherdefinieerd worden. Het tweede belangrijke mechanisme is de ontwikkeling van technische alternatieven die niet volledig in het bestaande regime passen. Dit kan pro-actief gebeuren door actoren die in het bestaande regime een belangrijke rol spelen maar kan ook plaats vinden in ‘beschermde ruimtes’ onafhankelijk van het bestaande regime.
Zodoende zijn drie typen activiteiten cruciaal voor de succesvolle transformatie van technologische regimes: het manifest worden van terugkoppelingen vanuit de omgeving van een technologisch regime (agressie en beroep), technische agendabouw en het ontwikkelen van technische alternatieven.
Tenslotte worden in het concluderende hoofdstuk de bijdragen aan het vakgebied technologiestudies besproken. De drie belangrijkste inhoudelijke bijdragen aan dit vakgebied zijn: 1) het belang van de mechanismen agressie en beroep bij de transformatie van technologische regimes; 2) het onderscheid tussen de vier innovatiepatronen en het belang van deze vier innovatiepatronen voor het begrijpen van techniekontwikkeling en 3) de rol van buitenstaanders in techniekontwikkeling.

In de epiloog wordt ingegaan op de vraag hoe betere vormen van techniekontwikkeling gedefinieerd en gerealiseerd zouden kunnen worden.