# Beyond energy efficiency

## Actors, networks and government intervention
## in the development of industrial process technologies

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## Actors, networks and government intervention in the development of industrial process technologies

Meer dan energie efficiëntie

Actoren, netwerken en overheidsinterventie bij de ontwikkeling van industriële procestechnologieën

(met een samenvatting in het Nederlands)

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# Chapter 1

# Introduction

The main objective of this thesis is to gain insight into the process by which innovative energy-efficient process technologies for the manufacturing industry are developed. The underlying interest is to explore how government can stimulate the development of such technologies. Although our interest is in the ways in which government can intervene, we need to make a detour first in order to increase our insight into the process by which such technologies emerge.

Human-induced climate change is the result of the extensive use of fossil fuels within the energy system. On the one hand technology allows exploiting the fossil fuel resources of the earth. On the other hand technological development and innovative technology are commonly suggested as partial solutions to the problem of greenhouse gas emissions. In Section 1.2, we concentrate on industrial energy-efficiency improvement as one of the promising technological options for mitigating greenhouse gas emissions. In Section 1.3, we argue that it is worth making a detour in order to analyse in detail the development of specific industrial energy-efficient technologies. It is suggested to draw on technology studies for deriving a framework that can be used for analysing the empirical case studies. In Section 1.4, we state the aim of the study, pose the research questions and present the outline of the thesis. In Section 1.5, the choice for a case study methodology is explained and the selection of four technology case studies is discussed.

## 1.1. Climate change and innovative technology

### Technology and climate change

Ever since people became an established factor in the history of the earth, they have developed and used technologies to facilitate their survival and to make life easier. Since that time human activity and the development and use of technology have been connected [Basalla, 1987]. In our modern society, highly integrated systems of technology have become a fact of life. The agricultural sector, the manufacturing industry, the medical health system, the transport system, and the energy sector cannot do without technology. Our daily life is strongly interwoven with the use of technology.

The historical use of energy illustrates how technologies have become increasingly integrated in our society and how they have contributed to human well being. Industrialisation has shown how the increasingly intensive use of energy, especially fossil fuels, can raise productivity in other sectors [Rosenberg, 1994]. Modern societies have developed with the backing of fossil fuels which have provided energy in an accessible and concentrated form. Technologies for extracting, converting and using such fuels are well developed and widely known [Grubb, 1991; Grübler, 1998]. At present, energy systems covering both energy supply and end-use are highly dependent on fossil fuels[1].

The exploitation of fossil fuels has not only contributed to human well being, it has also led to increasing environmental pressure on the earth. Human-induced climate change is currently one of the most important environmental problems related to the use of fossil fuels[2]. The emission of carbon dioxide ($CO_2$), one of the most important greenhouse gases, is a direct result of our intensive use of fossil fuels throughout society. The emission of greenhouse gases leads to changes in the radiation equilibrium of the earth's atmosphere. This may induce large-scale changes in the world's climate.

## Innovative technology as part of the solution

It is only fairly recently that anthropogenic climate change has been widely perceived as a problem for society. The scientific community has been aware of the issue for several decades. The historical records concerning research into the earth's climate system go back to the Swedish chemist Svente Arrhenius in 1895. During the second half of the 20$^{th}$ century, scientific research into climate change gradually increased. At the first World Climate Conference held in Geneva in 1979, the participating scientists recognised climate change as a serious societal problem. A series of meetings followed. The 1985 conference in Villach was a milestone in the climate debate because it succeeded in putting the climate issue on the international policy agenda. After that, anthropogenic climate change figured more and more prominently on the policy agenda. Concerns about the impact of future greenhouse gas emissions spurred governments on to draft and sign the Framework Convention on Climate Change in Rio de Janeiro in 1992. A series of meetings of the Conference

[1] The energy system, which comprises a sequence of conversion and transportation operations, can be divided into an energy supply and an energy end-use system. An energy system exists to serve end-users in fulfilling energy services [De Beer, 1998].

[2] Note that in additional to environment problems like human-induced climate change, the energy systems also cause problems. The reliance on fossil fuels is a challenge to geo-political stability and causes economic vulnerability since fossil fuel resources, especially oil, are located in specific regions of the world. The concept of a sustainable energy system has a broader connotation than only reducing environmental impacts. Sustainable energy is energy produced and used in ways that support human development over the long-term in all its social, economic and environmental dimensions (see e.g. [WEA, 2000]).

of the Parties (CoP), the supreme body of the Framework Convention, was organised after the Convention had been signed[3]. While these international political negotiations are ongoing (not always very smoothly), the climate problem is being quoted frequently as an argument for intensifying energy policy in various countries. Discussions have intensified over the last ten to fifteen years [Farla, 2000].

Innovative technology and technological development form an important part of the action that can be taken or stimulated by government to mitigate climate change (see e.g. [Nacicenovic, 1993; Grubb et al., 1992; IWG, 1997; IEA, 1997b]). Innovative technologies may facilitate the transformation of the energy system into a more sustainable practice by reducing $CO_2$ and other greenhouse gas emissions [WEA, 2000; Margolis and Kammen, 1999b; Hoffert et al., 1998; Kemp, 1997]. With respect to the most important greenhouse gas, $CO_2$, a wide variety of technology options have been suggested: energy-efficient and material-efficient end-use technologies, low or no carbon energy supply options (such as solar energy, wind energy, biomass energy and nuclear energy), and carbon sequestration (see e.g. [IPCC, 2001; WEA, 2000; Phylipsen, 2000; Blok et al., 1995; Turkenburg, 1995; Nakicenovic et al., 1993]).
It is almost paradoxical that on the one hand the use of technology associated with the exploitation of fossil fuels is an important contributor to human-induced climate change, while on the other hand innovative technology is also increasing the possibilities for remedies [Grübler, 1998; Foray and Grübler, 1997]. Some argue that technological development and innovative technology are the decisive factors in how cheaply countries are able to meet collective climate change objectives (see e.g. [IEA, 1996; Grubb, 1997; Edmonds et al., 1997]). Many national governments have focused their strategies for greenhouse gas mitigation on encouraging technological development [IPCC, 2001]. The recent third assessment report of the Intergovernmental Panel on Climate Change (IPCC[4]) for instance states: *"Innovation may lead to improvements in technology performance, reduction in greenhouse gas emissions per service provided, or reduction in cost for low-greenhouse gas technology, all of which can contribute towards green house gas mitigation" [IPCC, 2001, Ch. 5, p.10].*

The hope and expectation are that in the long run technological development and innovative technology will bring about tremendous improvements and resolve the apparent current conflict between environment and economy [Jaffe and Stavins, 1990; Jaffe et al., 2000].

[3] For a more elaborate account on the scientific and political history of the issue of climate change, see [Van der Sluijs, 1997; Phylipsen, 2000].
[4] The World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The aim of the IPCC is to assess the scientific, technical and socio-economic information relevant for human-induced climate change on a regular basis.

### A role for government in accelerating technological development

Technological development and innovative technology may make an important contribution to a more sustainable use of energy and thus to the mitigation of climate change. The large environmental (and economic and security) benefits of technological development and innovative technologies in the energy system are said to legitimise a more active role for government in the stimulation of energy R&D[5] (see e.g. [WEA, 2000; Margolis and Kammen, 1999b; PCAST, 1997]). Increasing the rate of technological development is one of the major challenges of our time [Blok, 2000]. The World Energy Assessment Council (WEA) recently wrote: *"there is the need to accelerate the energy innovation process through all effective means, including appropriate public policies where they can be identified" [WEA, 2000, p. 429]*. This raises the question of how government can contribute towards the accelerated development of desired technology.

Grübler, who wrote an extensive textbook on technology and global change [Grübler, 1998], also concluded that stimulating technological development is an important contingency policy in the case of uncertain issues such as climate change. However, he stresses that there is no simple answer to the question of which policy instruments or government intervention strategies should be used to follow such a technology strategy [Grübler, 1998, p. 358].

There is a growing amount of literature on the effects of policy instruments on technological change (including R&D, innovation and diffusion), although most of it has been theoretical. Empirical analyses of the effect of policy instruments on the rate and direction of technological development are limited in number [IPCC, 2001; Jaffe et al., 2000][6].

## 1.2. Innovative industrial energy-efficient technology

In the thesis we focus on the end-use of the energy system and, more specifically, on energy efficiency in the manufacturing industry. This is one of the important technological options always included in studies on possible ways of reducing

[5] Over the past few years, there has been a growing interest in understanding trends in energy R&D. Researchers have been looking for the explanations for and determinants of energy R&D expenditure levels. This interest is related to the question of whether industrialised countries and their governments spend enough R&D to address the threat posed by climate change and whether government R&D support has any effect [IEA, 1997a; Dooley et al., 1998; Margolis and Kammen, 1999a; Margolis and Kammen, 1999b; PCAST, 1997].

[6] The core of such theoretical analyses is rooted in economic literature and focuses on adoption (diffusion) rather than on technological development (see e.g. [Verhoef and Nijkamp, 1999; Fischer et al., 1998; Jung et al., 1996; Milliman and Prince, 1989]). Empirical research as reported for instance in Jaffe and Stavins (1995) and Kemp (1997) also focuses on technology diffusion rather than on technological development [Jaffe et al., 2000].

greenhouse gas emissions (see e.g. [IPCC, 2001; WEA, 2000; Blok et al., 1995; Nakicenovic, 1993]). We have three arguments.

## Long-term potential for energy-efficiency improvement

The worldwide manufacturing industry is the largest energy-consuming economic sector. The industry accounts for over 40% of primary energy end-use and carbon dioxide emissions (see Figure 1).

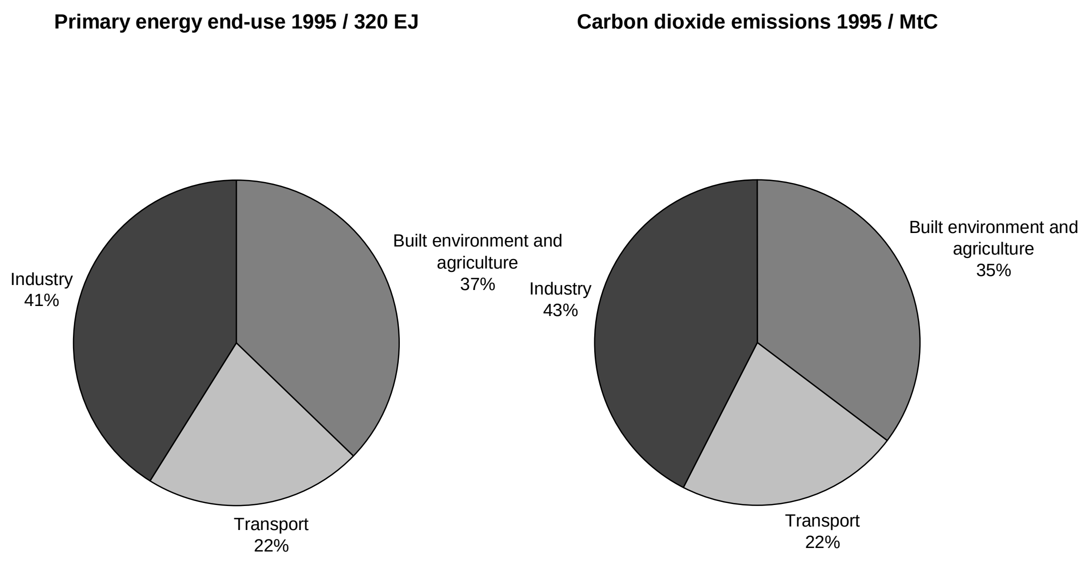


*Figure 1: World primary energy end-use and carbon dioxide emissions in 1995 [IPCC, 2001].*

Within the manufacturing industry, a considerable amount of energy is needed for the production of cement, steel, pulp and paper, fertiliser, petrochemicals, glass, aluminium and copper. The energy consumption in the iron and steel industry, the chemical industries, petroleum refining, pulp and paper and the cement industry are responsible for 45% of the total industrial energy consumption. The production of such basic materials is expected to remain a major energy-consuming activity in the future [WEC, 1995]. We concentrate on these energy-intensive manufacturing industries.

Energy system analysis, or energy analysis, which has emerged as a scientific discipline since 1970[7], has proven to be an indispensable tool for estimating the

[7] Energy system analysis studies the entire energy system, both the production of energy and the energy end-use within the society. The scientific discipline of energy analysis has developed in direct interaction with societal changes and trends in energy use. The origin of energy analysis is rooted in the scarcity of fossil fuels and the energy crises during the seventies. Since the early nineties, the issue of climate change has become the leading theme in energy analysis (see [Blok, 2000]).

potential for energy-efficiency improvements in the manufacturing industry [Phylipsen, 2000; Blok, 2000]. The potential for energy-efficiency improvement by implementing available technologies has been studied extensively (see e.g. [ETSU, 1984; Jackson, 1991; Mills et al., 1991; Blok et al., 1993; De Beer et al., 1994]). More recently, there has been increased interest in the longer term potential for industrial energy efficiency [Blok et al., 1995; Reddy et al., 1997]. Emerging innovative industrial energy-efficient technologies have been identified and characterised (see e.g. [De Beer, 1998; Martin et al., 2000]). Manufacturing industries continue to find new, more energy-efficient processes, which make this option important for the longer term too [IPCC, 2001].

### Industrial energy efficiency does more than simply save energy

Industrial energy-efficiency improvement is also seen as an attractive option for dealing with climate change, because it is acknowledged to be a cost-effective option for reducing $CO_2$ emissions [Grubb, 1991; Reddy et al., 1997; IPCC, 2001]. Energy efficiency is seen as a means of protecting the environment while promoting economic prosperity by savings costs [Doelen, 1989]. Manufacturing firms cannot only prevent emissions, but they can also enhance their profits by reducing energy use. Society needs to exploit the full economic potential of energy-efficiency improvement in order to benefit from the lower cost of providing energy services, to reduce adverse environmental impacts and to free capital resources for other purposes [WEA, 2000].

### Governments find industrial energy efficiency an attractive R&D option

Governments consider the development of innovative energy-efficient technologies for industry an attractive option for reducing greenhouse gas emissions. Whereas spending on government energy R&D support has generally fallen off, government R&D support for end-use energy efficiency has been increasing since the middle of the eighties (see also Figure 2) [WEA, 2000]. In industrialised countries industrial energy-efficiency R&D support appears to be receiving preferential treatment compared to other end-use sectors such as buildings or transport [Luiten and Blok, 1999; IEA, 1997a; Dooley et al., 1998].

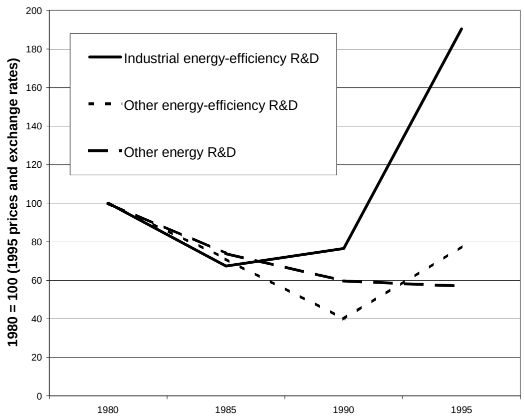


*Figure 2: Government energy R&D expenditure trends 1980 and 1995*[8] *[IEA, 1997a]. We have included the 11 countries for which data were available for each year*[9].

## 1.3. The need of a detour: Taking into account actors and dynamics

### Why a detour?

So far, we have seen that developing innovative industrial energy-efficient technologies is one of the appealing options for reducing future greenhouse gas emissions. The expectations concerned with innovative technology are large. The effect of government intervention in developing climate friendly technologies is however an unexplored area for empirical research.

At first sight, determining the effectiveness of government intervention is not very problematical. The ‘input’ has to be related to the ‘output’ or ‘impact’ of the policy instrument. The crux is what did government achieve by implementing a certain policy instrument? What would have happened in the absence of that instrument? In

[8] The International Energy Agency (IEA) collects and reports public R&D expenditure in energy R&D within the OECD countries [IEA, 1997a]. The IEA data are the best energy R&D available, although it should be realised that there are difficulties in data collection and data processing (see e.g. [Dooley et al., 1997]). The energy R&D data are at best an input measure. They say nothing about productivity. Furthermore, it should be noted that that R&D that affects energy end-use is not the same as ‘energy-efficiency R&D’ as distinguished in IEA statistics [Dooley, 2000]. Private sector energy R&D data are difficult to assess accurately [PCAST, 1997; Dooley, 2000; Sagar, 2000].

[9] Countries included are Canada, Denmark, Germany, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, and the US. On average 85% of the reported industrial energy-efficiency R&D is included; in the case of energy-efficiency R&D and energy R&D 87 and 89% respectively were included [IEA, 1997a].

the case of the improvement of industrial energy efficiency this implies that the policy instrument has to be related to the amount of energy saved due to that instrument.

In the evaluation of policy instruments for stimulating the *implementation* of existing industrial energy-efficient technologies, two important criteria are commonly used (see e.g. [CPB, 1997; Glasbergen et al., 1997; IPCC, 2001]):

- Effectiveness - the degree to which a policy instrument contributed to achieving a specific target, for instance, to what extent did the instrument contribute to improved energy efficiency (indicated in joules saved)?
- Efficiency - cost/benefit ratio of the policy instrument. The efficiency is the relation between the effectiveness and the means, which are required to achieve that effect. With regard to industrial energy efficiency, the efficiency is determined by the cost of the instrument per amount of energy saved.

Although the two criteria are clearly defined, assessing them empirically is a complicated task (see e.g. [Rietbergen et al., *forthcoming*]). The crux is to isolate the effect of the instrument from other factors and autonomous trends. Analysts start from plausible assumptions or calculations about the behaviour and reactions of *actors* with regard to investment in energy-efficient technologies. This is an important step in allocating the 'output' in terms of energy saved to the policy instrument evaluated[10].

Isolating the effect of the policy instrument in stimulating R&D and technological development is even more complicated because of the considerable time lag between the moment of intervention and the final impact[11]. There are some important problems in relating 'input' to 'output' [SPRU, 1996; Williams, 1993; OECD, 1997]. Some aspects can be easily measured, like financial input measures such as R&D expenditure and intermediate outputs such as number of scientific or technical articles, number of patents etc. However, input measures such as government R&D support do not indicate anything about the additionality of government intervention. Intermediate outputs may be related to government intervention but do not say anything about the final impact, for instance in terms of energy-efficiency improvements. The time lag between the moment of government intervention and the final impact of an innovative technology is such that many things can happen that may disrupt or enhance investments in R&D, technological development and innovation. It is difficult to estimate the importance of (earlier) fundamental R&D in

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[10] Regarding the investment behaviour of industrial firms in proven industrial energy-efficient technologies, insight into firms' behaviour and decisions is growing. This allows analysts to make plausible assumptions about the impact of a policy instrument on the investment in energy-efficient technologies (see for instance [Rietbergen et al., *forthcoming*]).

[11] There is a considerable amount of (scientific) literature on the difficulties of assessing the *final* impact of R&D investment in general and of R&D expenditure supported by government (see e.g. [CPB, 1999; SPRU, 1996; Williams, 1993; Smith, 1992; OECD, 1997]). A number of methods have been suggested for assessing the intermediate and final impacts of R&D; these include peer review, user surveys, cost-benefit methods, case studies, bibliometric indicators (e.g. patent analyses), generic science and technology indicators, and econometric models.

technological development. Spill-over effects usually occur in unpredictable ways. Achievements in process development may also lead to activities and modifications in fundamental R&D. Sometimes the impact of R&D activities is difficult to measure; the effect can be to establish links among actors, provide access to equipment, deliver advice or information, facilitate informal co-operation or lead to some improved control of existing technologies. A final, though major complication is that in order for R&D and technological development to come to commercialisation more is needed than investment in R&D. In other words, in evaluating the effect of government intervention in stimulating technological development one encounters a problem of attribution.

There is no insight into actors' arguments for being involved in the development of innovative industrial energy-efficient technologies. It is neither clear how government intervention affects actors' R&D decisions. Why do actors initiate, pursue or stop the development of industrial energy-efficient technologies? How susceptible are they to government's attempts to stimulate such developments? What are the other factors and dynamics at stake?

It is therefore worth taking a closer look at the development of such energy-efficient technologies in order to see what role government intervention played in the development of energy-efficient technology in particular case studies.

Therefore, we intend to make a detour. We will not start by evaluating policy instruments or government intervention strategies, but we will first obtain a better understanding of the role of actors and of the dynamics in the process by which industrial energy-efficient technologies develop. The basic idea is that the analysis of various detailed technology case studies will help us to make some suggestions for government intervention. Case studies let us examine the link between R&D activities, government intervention, actors' decisions and the actual development and materialisation of the technology. We want to understand what influences actors' decisions regarding technological development. We want to know how important energy efficiency is as an argument for developing an innovative process technology.

In making this detour we draw on two scientific disciplines, energy analysis and technology studies. As was indicated, energy analysis has greatly enhanced our insight into both short-term and long-term improvements in industrial energy efficiency. However, the way energy analysts perceive innovative technology and technological development is unlikely to be sufficient for gaining insight into the process of developing such technologies. Therefore, we suggest to take a look at the insights generated by technology studies for obtaining guidelines for the performance of the technology case studies.

## Energy analysis

In energy analysis, generally, a bottom-up strategy is adopted to analyse the amount of energy needed to fulfil various energy services[12]. The method starts from the demand for energy services. It is recognised that the same energy service can be produced with different levels of energy use depending on the technologies used for fulfilling the energy service. The specific energy consumption (SEC) is the amount of energy required to realise the activity associated with that energy service [De Beer, 1998]. With regard to industrial energy efficiency the activity is defined in physical terms, e.g. tonnes of paper or steel. Improvements in industrial energy efficiency can be translated into a reduction in the specific energy consumption. Information is collected about all kinds of technologies that reduce the specific energy consumption; these reductions together constitute the potential for energy-efficiency improvement (see e.g. [Martin et al., 2000; IWG, 1997; De Beer et al., 1994; ETSU, 1984]). Figure 3 portrays the way in which energy analysts typically perceive technology and the long-term potential for industrial energy-efficiency improvement.

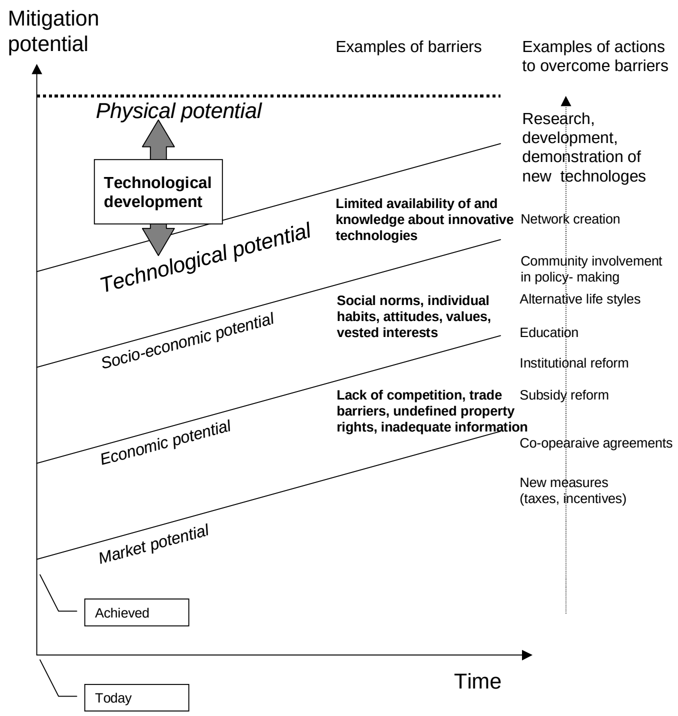


*Figure 3: The barrier model (reproduced from [IPCC, 2001, Ch.5]). A barrier is defined as any obstacle to realising a potential that can be overcome by a policy, a programme or a measure.*

[12] Energy analysts study industrial energy efficiency. They compare and explain differences in energy consumption per unit of activity (SEC) between countries (see e.g. [Farla, 200; Phylipsen, 2000]) and they assess the long-term techno-economic potential for energy-efficiency improvement (see e.g. [De Beer, 1998]).

Figure 3 shows that what is called the physical potential for energy-efficiency improvement in industry is ultimately limited by thermodynamic laws (see also [De Beer, 1998; Jochem, 1991]). The technical potential is what can be achieved by applying the best available technology to fulfil a certain energy service at a certain moment in time. The idea contained in Figure 3 is that the current technical potential can be increased in the direction of the physical potential by developing innovative technologies. To enhance technological development, the barriers that hamper the development of innovative (energy-efficient) technologies need to be broken down. This barrier model provides energy analysts with the logic for increasing government support of energy-efficiency R&D. The question that is usually ahead is: Do we have the potential to reduce $CO_2$ emissions by X% in the year Z? If the answer is ‘yes’, the targets can be set and the barriers obstructing the potential can be analysed in order to select policy instruments that break down these barriers. If the answer is ‘no’, a plea is made for enhanced R&D activities in order to get closer to the physical potential [Shove, 1998]. The neo-classical economic argument of market failure is typically quoted as a reason for enhancing public R&D activities[13]. The recent IPCC report (2001) for instance suggests that: *“The technical potential can be enlarged by solving scientific and technological problems. Policies to overcome this type of barrier must be aimed at fostering R&D” [IPCC, 2001, Ch.5, p.9].* R&D can have separate goals depending on the barriers that have to be tackled before a technology can be implemented. R&D can be performed to make a new technology technically feasible, to improve the technology in order to make the cost of application acceptable, or to explore and alleviate the barriers to the implementation of technology [Blok et al., 1995].

Energy analysts have a particular perception of innovative technology and technological development (based on [Rip and Kemp, 1998; Weber, 1997; Shove, 1998; Janda, 1998])[14].

First of all, the way of portraying technological development is rather linear and mechanistic. Once barriers are overcome the innovative technology flows automatically in the direction of commercial application. There is focus on R&D and a strong belief that R&D will provide change for the good or, for instance, the desired as improved energy efficiency. A typical quote is that *“R&D will likely increase the potential for energy-efficiency improvement and will reduce the costs for innovative technology” [IWG, 2000, p. 5.20]* and *“If R&D is successful, and the technologies are available and cost-effective, then the policies (to implement the*

[13] The market fails in the development of high-risk innovative technologies that require extensive R&D (propensity to under-invest in public goods). The differences between private rate of return on R&D expenditure and social rate of return reinforce this argument. The market also fails when full costs are not properly reflected in market prices as is the case with the negative externalities of energy use (see e.g. [UN, 1997; Margolis and Kammen, 1999b; WEA, 2000; IWG, 2000; PCAST, 1997]).

[14] The concept of potential has a strongly normative foundation. There could be more energy efficiency because it is technically feasible, and there *should* be more energy efficiency because non-adoption implies waste [Weber, 1997].

*technologies (EL)) need far less aggressive a push" [IWG, 2000, p. 1.59].* A recent report on emerging energy-efficient technologies recognises that *"R&D offers possibilities to reduce risks and lower capital investments costs" [Martin et al., 2000, p. 14].*

Secondly, for the purpose of their system analyses, energy analysts often restrict innovative technology to a specific piece of hardware with certain performance characteristics. Artefacts have clear-cut characteristics. Innovative energy-efficient technologies are listed and characterised by a number of indicators, such as their investment cost and the energy use compared to a reference technology. Innovative technologies are modelled in a technical way; innovative technologies are incorporated to show for instance how large the energy-efficiency potential is and at what cost it can be implemented in order to solve environmental issues.

## Technology studies

The above can be summarised by stating that energy analysts tend to *black box* both the process of developing innovative technologies and the innovative technologies themselves. They separate the technical from the social. This, of course, helps their specific analyses. However, it does not provide adequate insight into the process of developing energy-efficient technologies. Government intervention strategies do not affect technologies or hardware, but they do affect the actors developing the technologies. In other words, we need to open the black box. How is innovative technology constituted and how and why do actors become involved in developing them? We draw on technology studies, because this scientific discipline has developed detailed knowledge, both theoretical and empirical, about what is 'inside' the black box.

Scholars of technology studies have a perception of innovative technology and technological development that differs from these of energy analysts. The former explicitly reject the linear model of technological development. It is too simplistic to cover the interdependencies and interaction among actors in the process of developing innovative technologies. In addition, scholars in technology studies do not recognise an inherent logic in developing technology; it is the outcome of the choices made by actors rather than a force in itself. They try to understand what guides or constrains technological development. In order to do this, the evolution of the technological and social context is explicitly linked. The match between technologies and their social and economic context determines how actors conceive innovative technologies, what financial resources are spent on developing them and whether they will ultimately be adopted by actors and society.

## 1.4. Objective and outline of the thesis

The aim of the thesis is to gain insight into the process by which innovative energy-efficient process technologies for the manufacturing industry are developed. The underlying interest is to explore how government can stimulate the development of such technologies.

We decided that we need a detour and detailed technology case studies. Case studies are an established research methodology used in our type of explorative research. We are interested in the nature of a certain phenomenon rather than in the extent to which certain phenomena occur. An important part of the thesis thus consists of detailed empirical analyses of the networks within which four specific industrial energy-efficient process technologies are developed. For more detailed reasons for the choice of our case study methodology and for the selection of the four technology case studies we refer to Section 1.5.

This research aim raises three specific research questions:

1. How can the process of developing industrial energy-efficient technologies be characterised in terms of networks and actors, including the role of government?
2. How did four specific industrial energy-efficient process technologies develop and what role did government play in these case studies?
3. How can government stimulate, or accelerate, the development of industrial energy-efficient technologies?

The first two research questions form the heart of the empirical research work in the thesis. The first question requires a framework for the empirical case study research. This is developed in Chapter 2. We summarise the major insights resulting from the various approaches in technology studies. We also discuss what has been written about the effect of various policy instruments on technological development. Finally, we arrive at a framework for analysing the process of developing industrial energy-efficient technology in the subsequent chapters. The second research question is answered for each empirical technology case study. In Chapters 3 to 6, the development of the four industrial process technologies are described and analysed. The effect of government intervention is explicitly evaluated as part of the social shaping of the technology. In Chapters 3 and 4, we present the development of two energy-efficient technologies in the pulp and paper industry. Chapters 5 and 6 contain two energy-efficient technologies in the iron and steel industry.
The third research question covers the more explorative and final part of the thesis. Here, we return to our research interest in government intervention. In Chapter 7, we explore possible ways in which government can stimulate the development of industrial energy-efficient process technologies. We first compare and contrast the insights gained from the four technology case studies. We also summarise some contributions to technology studies and energy analysis. Finally, we present some

policy-relevant conclusions and come to some recommendations for government to stimulate the development of industrial energy-efficient process technologies. In Chapter 8, the results of our analysis are summarised.

## 1.5. Case study methodology

### Multiple comparative case study

We make a detour in which we analyse the process by which industrial energy-efficient technologies emerge. In this exploration of the empirical world, we want to understand how these innovative technologies develop. We want to understand the nature of a certain phenomenon rather than in the precise extent to which certain phenomena occur.
According to Yin (1989), a case study can be defined as an enquiry that investigates a history of a past or contemporary phenomenon within its real life context, when the boundaries between phenomenon and context are not clearly evident and multiple sources of evidence are used. Case studies are suitable for increasing our understanding of the context in which actors act and the influence the context has on actors' activities. In the thesis, the phenomenon studied is the process of developing industrial energy-efficient technologies in terms of actors and networks. The role of actors and dynamics cannot be studied in an experimental setting with controlled conditions. The distinction between the phenomenon and the context is not very clear. Moreover, contextual factors may directly affect the decisions that actors make regarding their involvement. The relation between technological development and the context in which the technology is developed is subjected to analysis. Our research is explorative; the theory is too premature for a (quantitative) testing of pure hypotheses. As we try to discover how industrial energy-efficient technologies develop, we do not know beforehand the specific variables that are going to be measured and how the different variables are connected.

In a methodology based on case studies, single and multiple case studies can be distinguished. In a multiple case study, separate case studies can be distinguished that provide similar information about the phenomenon studied. We choose to perform a multiple case study so that we can learn by contrasting and comparing specific technology case studies. Yin (1989) claims that by replicating the analysis in various case studies the evidence generated is more robust and can thus lead to stronger claims. Our evidence is derived from a detailed analysis of four specific technology case studies.

The major disadvantage of research based on case studies is that the logic of statistical generalisation does not apply. Generalisation of case study results can therefore only be based on analytical grounds, i.e. making plausible that the findings can be generalised. To make it plausible that the insights gained can be valuable in other situations, case study research has to guarantee validity. Validity refers to the correctness or credibility of a description, conclusion, interpretation or an explanation. There is a distinction between external validity and internal validity. External validity refers to generalisability of the research beyond a specific technology case study, whereas internal validity refers to the validity of the conclusions of each separate technology case study. Researchers have to ensure that their case studies have internal validity, so that insights are delivered that are more widely applicable (external validity). A qualitative case study methodology can guarantee just as much validity as quantitative research. Validity is made plausible by the empirical evidence, not by the type of research methodology adopted. The researcher has to rule out the threats that can lead to invalid conclusions and to invalid generalisations. When performing a multiple comparative case study, a researcher should try to maximise validity by [Maxwell, 1996]:

1. A proper selection of theories and concepts
2. A careful selection of case studies
3. A careful data collection and a secure data analysis

### Selection of theories and concepts

Our detour lets us view technology studies as a valuable source of theoretical and empirical information about technological development. In Chapter 2, we look at the various approaches adopted in technology studies in order to develop a framework that can be used to characterise and analyse the empirical material. The leading question is what should we look for in the empirical material.

Theoretical development in technology studies is still in its infancy [Edquist and Hommen, 1999]. However, the various approaches are a source of inspiration for exploring the empirical material. The approaches help us to frame the empirical analysis in terms of actors and networks. We derive case study questions that guide us in performing and analysing the empirical case studies. In this way, we introduce uniformity into the performance and analysis of the four technology case studies. We refer to Chapter 2 for a more detailed elaboration on the selection of theories.

### Selection of case studies

The unit of analysis in the case studies is the development of sector-specific energy-efficient process technologies. In the selection of the four technology case studies we strived for a balance between variety and comparability by selecting two technology case studies from two energy-intensive manufacturing industries.

Selecting two technologies from one specific industrial sector reduces the variation in the empirical research. Theoretically this reduces the external validity of the research. However, it increases our insight into whether certain results are technology-specific or sector-specific. In this way we enhance the reliability of the conclusions for that specific industrial sector. If research findings in the two technology case studies of each sector are not in conflict, this makes it plausible that the technology case studies selected are representative and that our conclusions are not accidental. Selecting technology case studies from two different industrial sectors increases the variation in the empirical research. Increasing the variety generates a wider range of situations and increases the richness of the empirical material generated.

How did we come to select the four technology case studies? First of all, we selected two energy-intensive manufacturing industries. Secondly, we compiled a list of typical innovative energy-efficient technologies.

Step 1

A restricted number of energy-intensive sectors account for a substantial proportion of worldwide industrial energy end-use (see also Figure 1). These sectors are typically included in techno-economic studies (see e.g. [Phylipsen, 1998; De Beer, 1998; Worrell et al., 1997; IWG, 2000]). We concentrated on these energy-intensive manufacturing industries.

Pavitt's classification of innovating firms is well known in technology studies [Pavitt, 1984]. This classification was used to divide the energy-intensive manufacturing industries over four categories of firms. Pavitt defined these four categories in terms of three firm characteristics: what is the origin of firms' innovative technology; what are the requirements of users; and what are the possibilities for firms to appropriate R&D results. Pavitt was aware of the existence of interdependencies between the four categories and already indicated patterns of innovation among firms and sectors. Table 1 shows which energy-intensive manufacturing industries fall into which category of firms. Table 1 includes OECD data on direct and indirect R&D intensity. Indirect R&D intensities include the R&D imported in intermediate supplies. These illustrate the differences in the innovation patterns of the various energy-intensive industries.

Table 1 permitted us to select two manufacturing industries from two categories in order to increase variety. We selected the pulp and paper industry from the supplier-dominated category and the iron and steel industry from the scale-intensive category. By selecting these two manufacturing industries, the category of specialised suppliers was automatically included. Such firms typically deliver innovative technology to supplier-dominated firms and also to scale-intensive firms.

We had two reasons for selecting these two sectors. First, they are relatively homogeneous compared to the other energy-intensive manufacturing industries indicated in Table 1. Secondly, and more importantly, there is a considerable amount of knowledge available about these sectors in energy system analysis (see e.g. [IPCC, 2001; De Beer, 1998]).

*Table 1: Classifying energy-intensive manufacturing industry according to Pavitt's innovation taxonomy (1984).*

| **Innovation type firm** | **Industrial manufacturing sectors [ISIC Rev.3][1]** | **Energy-intensive** | **R&D-intensity[2]** | **Indirect R&D intensity** |
|---|---|---|---|---|
| Supplier-dominated | - Textiles, fur and leather [17-19] | | 0.23 | 0.55 |
| | - Pulp and paper [21+22] | X | 0.31 | 0.57 |
| Specialised suppliers | - Machinery [29] | | 1.74 | 1.84 |
| Scale intensive | - Mining [10-14] | | [4]- | - |
| | - Food and beverages [15+16] | | 0.34 | 0.39 |
| | - Basic chemical industry [241] | X | - | - |
| | - Iron and steel [271+2731] | X | 0.64 | 0.46 |
| | - Non-ferrous metals [272+2732] | X | 0.93 | 0.64 |
| | - Non-metallic mineral products [26] | X | 0.93 | 0.51 |
| | - Fabricated metal products [28] | | 0.63 | 0.72 |
| | - Motor vehicles [34] | | 3.41 | 1.03 |
| | - Other transport eq. [35][5] | | 1.58 | 1.45 |
| | - Utilities [40-41] | | - | - |
| Science based | - Mineral oil industry (PR) [23] | X | 0.96 | 0.37 |
| | - Chemicals and chemical products: | | | |
| | excl. basic chem. [24] | | 3.2 | 0.64 |
| | incl. pharm. [2423] | | 10.47 | 0.88 |
| | - Electro-technical industry: | | | |
| | Office & comp. eq. [30] | | 11.46 | 2.91 |
| | Electrical mach. [31] | | 2.81 | 1.15 |
| | Radio, TV & comm. eq. [32] | | 8.03 | 1.37 |
| | Scientific instruments [33] | | 5.10 | 1.45 |

[1] Classification based on [Pavitt, 1984; CBS, 1998]. [2] R&D intensity is the R&D expenditure divided over the production value of the industrial sector. Weighted average for ten countries (GDP purchasing power parities) [Hatzichronoglou, 1997]. [3] An input-output analysis leads to an R&D intensity that includes indirect R&D. The R&D investment by a supplying industry is divided over its total production value. Via input-output analysis this R&D is attributed to the sectors which buy certain products or goods from this supplying industry. The indirect R&D intensity thus includes the R&D that is supplied in intermediate products or goods [Hatzichronoglou, 1997]. [4] - = R&D intensities not available [Hatzichronoglou, 1997]. [5] Excludes Aerospace and Shipbuilding [Hatzichronoglou, 1997].

Step 2

We used a variety of sources[15] from the tradition of energy analysis to compile a gross list of innovative energy-efficient technologies for the pulp and paper industry and for the iron and steel industry. The following criteria were used for selecting four specific industrial process technologies from that list:

- We concentrated on sector-specific energy-efficient technologies. We do not include a case study concerning – what energy analysts call – a cross-cutting technology, which is an energy-efficient technology that can be applied in more than one sector (e.g. combined heat and power, energy-efficient motors, and heat

[15] [IPCC, 2001; Martin et al., 2000; IWG, 1997; Worrell et al., 1997; De Beer, 1998; Arthur D. Little, 1998; Blok et al., 1995; De Beer et al., 1994; Smit et al., 1994].

pumps). We chose sector-specific technologies for two reasons: first of all, they promise larger energy-efficiency improvements because they save energy in the core of the production process; secondly, exclusion of cross-cutting technologies is a way of maximising the comparability of technology case studies.

- The technology had to promise a step-wise reduction in the specific energy consumption (SEC) of a production process.
- Technology case studies had to be fairly recent. It is interesting to focus on technologies that may be of actual importance in reducing greenhouse gas emissions. Data accessibility was another reason for selecting recent technology case studies. Most of the technologies included in the lists of energy analysts are current technologies. A number of them are still being developed. Technology case studies should however have a long enough history of development to be of interest for our empirical research.

Table 2 gives an overview of the four technology case studies selected.

*Table 2: Overview of the case studies selected [De Beer, 1998; Martin et al., 2000].*

| **Case study** | **Sector** | **R&D started** | **Present status** |
|---|---|---|---|
| Shoe press technology | Pulp and paper | 1970 | Widely implemented |
| Impulse technology | Pulp and paper | 1980 | Claimed ready for commercial application, status is uncertain |
| Strip casting technology | Iron and steel | 1985 | Claimed ready for commercial application |
| Smelting reduction technology | Iron and steel | 1985 | Claimed ready for commercial application |

## Data collection and data analysis

There are also threats to validity in data collection and analysis. We used two strategies, triangulation and member checks, in order to rule out these threats. Triangulation is testing and cross-checking data which have been collected from various sources. A case study methodology typically combines information from various sources. Both data collection and data use have to be handled with care. A second strategy for ensuring validity is member checks. The researcher systematically solicits expert feedback about his or her analysis and conclusions [Maxwell, 1996].

We used two main sources of data: written material and interviews with experts.

<u>Written material</u>
All kinds of written material - scientific articles, technical articles, articles from trade journals, conference proceedings, technical reports, patents, statistics and press

releases - were used. Written material was typically used to make a first factual mapping of the R&D activities and the actors involved (especially questions as who was involved, when, what kind of equipment who did one use and what were the performance claims). Patent databases were used to check the completeness of the network. A preliminary list of names of experts to contact was also derived from written material. Finally, written material provided a means of checking the data and information gathered in expert interviews.

Interviews

An important part of the data and information was gathered in interviews. Experts who were (or are) involved in developing the industrial energy-efficient technologies were interviewed. Consultation with experts is an essential part of our empirical research, because the data and information we were looking for were often not available in written (public) material. We conducted personal interviews, had elaborate telephone conversations, and used e-mail. The interviews were semi-structured. The framework provided us guidelines for the performance of the technology case studies. A list of case study questions was formulated (see Chapter 2). Consultation with experts is a valuable source of data, although the researcher should critically deal with the reliability of statements made by experts. A written draft of the interview was sent to the expert interviewee accompanied by a request for his or her comments. In order to increase the reliability and to circumvent well known pitfalls such as selective and faded memories, vested interests and secrecy, information and statements were tested against statements made by other experts and against written sources. We consulted a large number of experts for each case study and tried to include representatives of all actors that were involved in the development of the specific industrial process technology.

In case study methodology, both written and interview materials have to be carefully processed for two reasons. First of all, both sources have intrinsic limitations. Experts and interviewees give their interpretation of why and how things happened. This information and these statements have to be checked. Written material can also be biased because of the person who wrote the article. Not all data covered in articles are neutral or value-free facts. Secondly, as a researcher you are interpreting the data and information in written sources and the statements made and accounts given by the interviewees. As a researcher you are structuring the information so that the research questions can be answered. Data collection in qualitative research means reconstructing and gaining understanding at the same time. As the researcher collects data, he or she has to anticipate the insights that are and still will be gathered. Thus, data collection and data analysis overlap. It is important to organise data collection carefully. We therefore adopted the following procedure:

- We contacted most of the experts more than once. The first round provided basic information about other actors, networks, agendas and artefacts. It also delivered suggestions for articles and the names of other experts we could contact.

- Written material was collected to map the first outline of a technology's development.
- For each of the micro-networks, a description was made of the events and decisions that had taken place within that micro-network[16]. These descriptions were used in a second round of interviews with the experts.
- The material gathered for the various micro-networks was also grouped under separate topical headings (related to the case study questions, see Chapter 2) so that the various micro-networks could be compared and cross-linkages could be made. These descriptions were also used in a second round of interviews with the experts.
- The second round of interviews took place after the researcher had made a preliminary synthesis and analysis of the written material and the information and statements gathered in interviews. This second round was important for acquiring a proper understanding of the special peculiarities of the specific case. In this way, the researcher organised feedback, first of all on the information and insights obtained so far and secondly on his or her interpretations.
- A draft version of the chapter based on each specific technology case study was sent to the industrial experts in order to solicit feedback and their comments and suggestions.

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[16] See Chapter 2, Section 2.5 for an explanation of micro-networks.

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# Chapter 2

# Government intervention and technology studies: Towards a framework

## 2.1. Introduction

If we want to understand what guides or constrains R&D and technology so that it develops in certain directions, if we want to understand actors' arguments for developing the technology, and if we want to evaluate the role of government intervention, what should we look for in the empirical material? In this chapter we deal with our first research question: how to characterise the process of developing a specific industrial energy-efficient technology in terms of actors and networks, including the role of government? A framework is developed that can be used for analysing the empirical material in the subsequent chapters. The framework should provide us with some guidelines for the performance of the technology case studies.

Section 2.2 specifies what is meant by the process of developing industrial energy-efficient technology. In Section 2.3, we summarise what is known about government intervention strategies and policy instruments in directing R&D. We also define how the term 'effect' of government intervention is used in this thesis. In Section 2.4, various approaches in technology studies are discussed. In Section 2.5, we arrive at a framework for analysing the process of developing industrial energy-efficient technology.

## 2.2. Process of technological development

We are interested in the process by which innovative energy-efficient technology develops. What, then, do we really mean by the process of technological development?

A proven technology is the result of earlier invention and innovation and has become an established technology that is widely adopted and accepted. An invention is the initial idea, sketch, or model for a new or substantially improved device, product or process. An innovation is accomplished only with the first commercial transaction involving the new product, process, or device [Freeman, 1982]. Diffusion is the widespread adoption (or implementation) of an innovative technology[1]. Joseph Schumpeter (1934) was the first to distinguish diffusion from invention and innovation[2]. The sequence of invention-innovation-diffusion implies a rather linear model of innovation without interaction and feedback taking place between the different stages. This aspect has been criticised for instance by Kline and Rosenberg (1986), who suggested a chain-linked model of innovation instead [Rosenberg, 1982; Kline and Rosenberg, 1986]. Rosenberg emphasised that continuing technological improvements occur between the moment of invention and innovation and during the diffusion of the technology. When the modifications during diffusion become extensive the distinction between innovation and diffusion often becomes hard to draw. Technologies are continuously adapted and improved to better fit conditions and requirements.

Acknowledging this major criticism of Schumpeter's distinction and starting from a chain-linked or interactive understanding, scholars still use the concepts of invention, innovation and diffusion to indicate in what stage they are specifically interested (see e.g. [Rosegger, 1996; Kemp, 1997; Grübler, 1998; Ashford, 1999; Jaffe et al., 2000; Norberg-Bohm, 1999]). In our study of the process by which energy-efficient technologies develop, we look in detail at the R&D activities that are performed to bring an unproven technology to the market. In our empirical research we focus on how an innovative process technology is brought to the market, but we acknowledge that interactions and feedback occur between the various stages (as we will see, the diffusion stage has a major impact on the development of energy-efficient technologies)[3]. We use the two terms diffusion and implementation to indicate the spreading of an innovative energy-efficient technology across a certain manufacturing industry.

[1] Diffusion is very important from an economic and social point of view, because an innovative technology only pays off economically, environmentally or socially when it is applied and replicated.

[2] Schumpeter (1883 – 1950) is not the only one who should be credited with pioneering our thinking on technology. The economist Thornstein Veblin was the first to focus on the interactions between humans and their artefacts in an institutional context. He saw technology as a part of social relationships. Technology is developed and shaped by social actors and at the same time shapes social values and behaviour. He suggested a 'circular' model of thinking in which the technical and the social interact [Grübler, 1998; Van der Steen, 1999].

[3] In scientific literature, the term innovation is often used to indicate the entire process of invention, market introduction and further diffusion and optimisation. We use innovation to indicate the first commercially successful application of an innovative technology.

## 2.3. Government intervention

In this section, a sketch is given of the variety of intervention strategies by which government can enhance technological development. Possibilities for government intervention have changed over time as scientific insight into technological development has evolved and as the ways in which knowledge and R&D are produced, exchanged and used have changed [Smits, 2000; OECD, 1992; Branscomb and Florida, 1999; Caracostas and Mulder, 1998]. We examine various specific policy instruments and describe whether these instruments can guide R&D and technological development in desired directions. We also define how the term ‘effect’ of government intervention is used in this thesis.

### A variety of instruments and strategies

<u>An increasing number of policy instruments and intervention strategies</u>

Nearly all laws, regulations and other policies in a country may affect the development of innovative technologies[4] [OECD, 1998; Cannel and Dankbaar, 1996; Rothwell and Zegveld, 1981]. In many industrialised countries, government tries to enhance the national capacity for producing, transferring and exploiting R&D, knowledge and innovative technology (see e.g. [OECD, 1998; OECD, 1996]). The number and nature of technology policy instruments and intervention strategies have changed over time. Several authors have described various typical stages in the ways in which government has tried to stimulate R&D and technological development (see e.g. [Rothwell and Dodgson, 1992; Arendsen and Korsten, 1996; Caracostas and Mulder, 1998; Schilder, 2000]). Van der Steen (1999) describes these changes in technology policy as a policy learning process. It is useful to briefly discuss the stages in technology policy, because these help to explain the variety of policy instruments that are currently considered for directing technological development.

During the 1960s and 1970s, the focus for stimulating R&D and technological development was on the supply side or ‘science push’ side. The roots of government intervention can clearly be traced to science policies. Government intervened by generating knowledge through the stimulation of absolute investments in R&D in both private firms and national public research institutes for the purpose of improving the competitiveness of industry. In a second stage that started in the early 1980s increasing R&D expenditure was no longer regarded as an adequate measure for increasing the competitiveness of industry. The focus shifted to the under-exploitation of the new knowledge and technologies available. The idea emerged that generating knowledge was not enough; knowledge and innovative technologies needed be channelled to the firms that could use them. Access to new knowledge was

[4] For example: macro-economic policy, science and education policy, policies affecting investment climate and trading conditions.

improved by e.g. transfer- and innovation-centres, demonstration projects, and R&D subsidies to sector organisations. In a third stage, roughly from the early 1990s onwards, technological development began to be seen as a highly systemic and interactive process. Technological development implied more than science push and diffusing knowledge. It was recognised that technological development depends on the capacity of heterogeneous firms to develop, absorb and apply new knowledge in constellations of networks. Firms learn within a specific socio-economic context. Government intervention thus switched to stimulating learning and co-operation in an innovative climate. Interaction between actors is considered to be crucial. Co-operation spreads the risk and cost of R&D, assists in technology implementation by extending the number of firms involved, prevents replication of R&D efforts, and improves the return on public investments by increasing private sector involvement.

The dominant change in the philosophy of government intervention can be defined thus: government should aim at managing or facilitating the processes of interaction among relevant actors and creating the conditions which facilitate R&D activities and processes of technological development [Smits, 2000]. Technological development and innovation are seen as dynamic social processes that evolve most successfully in networks in which there is intensive interaction [OECD, 1999; OECD, 1998; Cannel and Dankbaar, 1996; Dodgson and Bessant, 1996; Caracostas and Mulder, 1998].

Government intervention can thus take a number of forms. Policy instruments can stimulate both the *supply* of and/or the *demand* for technological development and innovation. Instruments can be more *generic* and thus stimulate R&D and technological development to maintain the basic infrastructure or to enhance the competitiveness of the national industry. Instruments can also be more *specific*. Then, government tries to direct technological development. These two dimensions create a matrix of four intervention strategies. Specific policy instruments can be characterised along these two dimensions.

Box 1 gives an overview of the variety of policy instruments commonly used for guiding technological development in desired directions (such as improved energy efficiency). It shows the variety of policy instruments available and summarises what has been learnt about the way in which these instruments affect R&D and technological development. Each policy instrument is characterised by the two dimensions indicated in the former paragraph.

**Box 1: Policy instruments and their effects in directing technological development**

**Research priorities – Matching supply and demand; generic and specific**
By formulating research priorities, government articulates desired research areas. This may affect the R&D agenda of, for instance, universities and public research institutes or may lead to thematic R&D programmes such as improving the energy efficiency of the manufacturing industry. The effect aimed at is directing R&D towards desired, strategically relevant research areas.
Technology-foresight exercises, Delphi studies, demand-oriented sector studies, and Technology Assessment are examples of instruments which are used in the - often participatory - processes of formulating R&D priorities. Experts are consulted in order to select research areas of strategic importance for the future of industry or for solving environmental problems. The generation of R&D and knowledge is linked with the needs for knowledge in certain areas [Arthur D. Little, 1998; Kemp, 1997; Arthur D. Little, 1996].

**Technology standards – Demand; specific**
By prescribing or prohibiting specific technologies, government actively seeks the elimination of undesired technologies.
Technologies can be prescribed only if the performance is proven for the variety of firms confronted with the regulation. A major disadvantage of this instrument is that the differences in costs of compliance by different firms are ignored. In addition, it reduces the incentive for further R&D and technological development [Wallace, 1995; Rosegger, 1996; Kemp, 1997].

**Performance or emission standards – Demand; specific**
By formulating performance or emission standards, government formulates criteria that are likely to affect firms' decisions to invest in (the development of innovative) technology.
Such standards have been the most common method for reducing specific emissions or exposure to hazardous substances (though not in improving energy efficiency). Firms are flexible about how they can meet these standards. However, uniform standards still give rise to static inefficiency in the case of heterogeneous polluters as the cost of compliance may differ [Kemp, 1997; Rosegger, 1996; Wallace, 1995].
Some authors argue that emission and performance standards *favour diffusion* rather than technological development, because they are often based on the best available technologies [Kemp, 1997; Norberg-Bohm, 1999]. The most significant improvements in performance or reduced emissions occur in response to stringent regulations, which give firms some time to develop or optimise technologies. Thus, there appears to be a trade-off between quick results and more innovative solutions [Kemp, 1997]. There are also scientists who provide evidence that regulation is the *mother of invention*, provided that regulatory instruments are designed properly [Ashford, 1994; Porter and Van der Linde, 1995; Ashford, 1999]. To conclude, as the OECD already noted in 1985, the relationship between regulation and technological development is not a one-way relationship [OECD, 1985].

**Technology-forcing standards – Demand; specific**
Technology-forcing standards demand performance or emission levels that are not feasible with the existing technology. The requirements induce firms to invest in developing innovative technologies.
It is plausible that technology-forcing standards are a better instrument for encouraging technological development than emission or performance standards. Kemp (1997) claims that technology-forcing standards are especially promising in the case of innovative technologies that can be commercialised at moderate costs [Kemp, 1997].

*Box 1 continued on next page*

A drawback of technology-forcing standards is the threat of strategic behaviour on the part of firms. Firms are generally better informed about what is technologically feasible within a certain frame of time. Policy-makers have to assume that some amount of improvement is feasible and realistic within a certain time frame, although they are not certain how much. A complementary system of fines may be needed [Kemp, 1997; Wallace, 1995; Jaffe et al., 2000].

**Taxes, fees and tradable emission permits – Demand; specific**
By raising taxes or fees or by introducing a system of tradable emission standards, government tries to financially burden 'undesired' behaviour. Taxes, fees and tradable emission permits are a means of stimulating technology to develop in desired directions by changing the structure of financial incentives: negative externalities are taxed or positive externalities are rewarded.
Whereas the principle of market-based instruments is elegant and straightforward, there is no consensus about the advantages of market-based instrument over standards or command-and-control policies. Market-based policy instruments are generally advocated for their economic efficiency. Economists argue that incentive-based instruments provide a more continuous spur to innovation than command-and-control policies. The innovator is able to achieve an extra gain by a further reduction of the targeted emission, at least according to economic theoretical models that assume e.g. perfect knowledge[5] [Jaffe et al., 2000; Norberg-Bohm, 1999]. Empirical material indicates that in practice the price signals are often relatively small, so that the economics of a production process are not fundamentally changed [Kemp, 1997; Arthur D. Little, 1998; Norberg-Bohm, 1999]. Therefore, market-based instruments show advantages but should not be regarded as a panacea [Wallace, 1995].

**R&D support or subsidies – Supply; specific (can also be generic)**
By providing R&D support, government stimulates firms to invest in developing (innovative) technologies.
Government R&D support is one of the most common instruments for stimulating R&D and technological development, but also one of the most debated. Empirical evidence regarding the effect of R&D support is ambiguous. R&D support seems to be expensive, violates the polluter-pays principle, and may favour 'second-rate' projects [Kemp, 1997]. It is often hard to indicate the additional value of R&D support, since it is hard to know what would have been done without government R&D support [CPB, 1999]. Arthur D. Little (1998) claimed that R&D and demonstration subsidies may affect specialised research institutes and small firms such as specialised suppliers. With regard to large firms, R&D subsidies will hardly affect firms' decisions [Arthur D. Little, 1998]. According to Kemp (1997), R&D support or subsidies should be granted to technologies with a long time frame of development or to technologies that are easily imitated by others (there are problems in appropriating the benefits).

**Venture capital – Supply; specific (can also be generic)**
A lack of risk capital may be a bottleneck impeding the introduction and subsequent use of an innovative technology. By raising and providing venture capital, government tries to facilitate the final, capital intensive stages in technological development.
It is claimed that a supply of venture capital allows efficient spending of resources: when proposals are well screened, most of the loans will be paid back if the innovative technology is applied successfully. However, large sums of money are at risk for quite some time [Arthur D. Little, 1998].

*Box 1 continued on next page.*

[5] There are more recent economic models with revised assumptions which are give a differentiated view on the superiority of market-based instruments over regulatory instruments (see e.g. [Verhoef and Nijkamp, 1999; Fischer et al., 1998]). If various market-based policy instruments are compared, e.g. taxes and tradable permit systems, results are less consistent (see e.g. [Milliman and Prince, 1989; Jaffe et al., 2000]).

**Voluntary (R&D) agreements – Matching supply and demand; specific**
Government may try to stimulate technological development by negotiating agreements with industries in which they commit themselves to reduce for instance environmental emissions or improve energy efficiency within a certain time frame. A commitment to R&D and technological development can be part of the agreement.
Voluntary agreements are attractive to industry because they give participants freedom regarding the method and moment of compliance. The largest disadvantage of agreements is the possibility of strategic exploitation of the agreement. Individual firms may for instance show free-rider behaviour in a collective agreement [Kemp, 1997; Arthur D. Little, 1998]. So far, little experience has been gained with regard to the inclusion of agreements on R&D in voluntary agreements[6]. Such government-industry R&D agreements devolve greater responsibility to industry, lead to more flexibility to innovate, and lower compliance costs. Another threat to R&D agreements is that firms are generally more aware than government of the technological possibilities [Kemp, 1997; Wallace, 1995].

**Technology procurement – Demand; specific**
By guaranteeing a certain market demand, governments reduce the risks involved in bringing a technology to the market. Governments may e.g. establish procurement requirements with regard to energy use. This instrument is typically adopted to bring consumer products to the market. In the case of industrial sectors, such an approach is more difficult because industrial process technologies are less standardised and require higher investment costs than such commodity consumer products.

**Initiating and stimulating networks – Matching supply and demand; specific or generic**
By initiating networks and co-operation between actors such as firms and research institutes, government tries to enhance the match between the supply and demand of R&D and the actual exploitation of the knowledge and innovative technologies.
This instrument has been used more frequently since the early 1990s. Insisting on interaction and fine-tuning between various actors is often a design characteristic of other policy instruments. Co-operation is, for instance, often a condition for acquiring R&D support.
A possible drawback is that large firms do not feel the strong need for assistance in forming links and networks with other actors such as research institutes and universities; the necessary networks are already in place. They consider their own networks to be better developed than the ones created by governmental intervention. The value that firms place on stimulating networks depends on the nature of the technology concerned. When the technology is outside the core of the production process, government intervention in building networks tends to be perceived as more valuable [Arthur D. Little, 1998].

Box 1 first of all reconfirms what was already mentioned in Chapter 1. The effect of government intervention in developing climate-friendly technologies is an unexplored empirical research area. Box 1 shows that so far there are few empirical reasons for suggesting that any specific policy instrument is better at encouraging technological development in a desired direction than any other single policy instrument. Secondly, it is important to note that several authors suggest that the 'success' of a policy instrument depends on the context in which it is used. The intrinsic properties of a policy instrument alone cannot explain its effect in directing or stimulating technological development [Kemp, 1997; Norberg-Bohm, 1999; Wallace, 1995; OECD, 1985].

[6] The classic example of an agreement between US automotive industry and the US government in developing innovative technology is the Partnership for a New Generation Vehicle (PNGV).

Evaluating effect – taking the context into account

The context-dependency of the effect of government intervention is by now a well accepted phenomenon in policy studies[7] [Glasbergen, 1989; Bruijn and ten Heuvelhof, 1995]. Glasbergen (1989) argues that it is always possible to find examples of a policy instrument that is effective in one situation but not in another. This cannot be explained only by the intrinsic characteristics of the policy instruments; equally important are the characteristics of the context in which government tries to intervene.
The traditional model of government intervention, as favoured by the rational policy approach, assumed a central and controlling role by government. To put it somewhat simplistically, government could reach its policy goals simply by selecting the proper policy instrument. The policy network approach in policy studies stresses the dependencies between actors, government being one of them. In order to realise policy goals government is dependent on other actors. The idea of policy networks was first used to explain earlier government intervention failures, but more recently it has been suggested that policy networks also provide opportunities for government intervention. The suggestion is that the effect of government intervention can be increased if the characteristics of the policy networks are taken into account.
Two important levels of intervention can be distinguished. Government can try to modulate existing networks or it can try to change the composition of the networks in itself[8] [Glasbergen, 1989; Hanf and Scharpf, 1987; Verheul, 1999].

These recent developments in policy studies further support the idea of making a detour as suggested in Chapter 1. In our empirical research, the role of government and the effect of government intervention are explicitly included in each case study.

### Defining effect

In spite of the difficulties in measuring the effect of government intervention in stimulating R&D and technological development (as discussed in Chapter 1 and illustrated by Box 1), we have to be clear what we mean by 'effect'. After all, we use

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[7] The theoretical roots of policy networks are found in policy science (rational actor; bounded rationality; process model), organisational science (rational organisation, contingency approach, inter-organisational theory), and political science (pluralism, agenda research, political communities) (see e.g. [Hufen and Ringeling, 1990; Klijn et al., 1993; Klijn and Koppenjan, 1997]).

[8] Strategies have been suggested by e.g. de Bruijn and ten Heuvelhof (1991), de Bruijn and ten Heuvelhof (1995), Klijn and Koppenjan (1997) and Verheul (1999). The strategies try to exploit existing (business) dependencies between actors and to take into account the existing diversity between (and within) sectors and the diversity in existing competencies and resources of actors. Examples of strategies are: steer indirectly, steer interactively (multiplural), fine tune the instruments to a relatively homogeneous target group, manage existing networks rather than passively apply instruments, play a role in network building and constitution, selective activation of networks (devoted actors), strengthen or weaken dependencies among actors, and supply or withdraw (financial) resources.

this term in our empirical technology case studies. We also use it in Chapter 7 when we explore the possibilities for government intervention.

The choice for detailed technology case studies allow us to evaluate the effect of government intervention as part of the context within which energy-efficient technologies are developed. The detailed case studies in which we cover the dynamic and long-term process by which specific technologies develop make it possible to relate the ‘input’ to the ‘output’ or ‘impact’ of government intervention in a qualitative way. By covering the entire process it is possible to see how government intervention did actually affect the development of the technology. The effect of government intervention is explicitly evaluated as part of the social shaping of the technology. What was the role of a policy instrument in bringing an innovative technology to the market? How important was government intervention in achieving improved energy efficiency as a result of R&D and technological development? We make a distinction between three different aspects of ‘effect’:

- Additionality: Government intervention is additional if actors would not have started or continued R&D activities without government intervention. Additionality indicates whether government intervention had an effect at the moment when government intervention occurred. Additionality does not say anything about the continued effect of government intervention.
- Acceleration: Government intervention accelerates technological development if the progress of the development – worldwide – was faster than it would have been without government intervention. Additionality is a pre-condition of acceleration.
- Effectiveness: Government intervention is effective if it leads to improved industrial energy efficiency. This is achieved only if the technology is implemented in the end and if the firm-specific specific energy consumption is reduced.

## 2.4. Opening the black box[9]

In this section we look in more detail at the key lessons to be learnt from technology studies. We introduced technology studies as a scientific discipline that has produced detailed knowledge about what is inside the black box of technological development. Rosenberg (1982) was one of the first to use the metaphor of ‘opening the black box’. Not only economists, but also sociologists and historians have increased the understanding of what guides R&D and technological development go in certain directions and occur at a certain pace. The major challenge in technology studies is clearly to come to grips with the immense diversity of the contents of the black box [Rosenberg, 1982; Rosenberg, 1994].

[9] This section is derived from [Luiten and Harmsen, 1999].

The insights generated on what is inside the black box may help us to characterise the process by which industrial energy-efficient technology develops in terms of actors (including government) and networks.
In this section we do not intend to give a complete and fully detailed description of the various approaches in technology studies. We limit ourselves to the basic concepts and mechanisms. Our research aim induces us to be particularly interested in what affects the direction of technological development and in the possible ways in which government can influence technological development. Each of the approaches is summarised by indicating three key-points of interest:

1. How is technological development perceived?
2. What directs technological development?
3. What are the possibilities for government intervention?

### Neo-classical economic approach

Strictly speaking, this approach does not belong to the sphere of technology studies. In fact, the rather restricted view of technology within this neo-classical approach was one of the major factors that led to the emergence of technology studies. However, the neo-classical approach still provides the dominant rationale for government intervention in R&D and technological development. Therefore, it merits some discussion.
Mainstream thinking in neo-classical economy considers technology as an exogenous factor. Technology was falling like ‘manna from heaven’. Since the work of Abramovitz (1956) and Solow (1957) technological development has become a factor in neo-classical growth theories. At the macro-level, it is postulated as a residual of the production function. In other words it is what is left to explain economic growth after the effects of labour and capital have been accounted for. Introduction of an innovative technology is interpreted as a shift in the production function. The technology and also the process of developing technologies are still ‘black boxed’. Technology and technological development do not need to be explained themselves [Van Dijk and Van Hulst, 1988; Dankbaar et al., 1991].
The central assumption in the traditional neo-classical economic view is the existence of competitive equilibrium. Efficient allocation results in optimised welfare. If the conditions of a perfect market are met, the invisible hand of the market leads to efficient (re-)allocations. The organising principle is the economic rationality of the economic agents. Each agent maximises some known objective function. According to this neo-classical perspective technology is generic, codified, accessible free of costs and universally applicable[10] [Smith, 1995].

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[10] The more recent neo-classical new growth theories include innovation and knowledge generation as an endogenous part of their economic models. Attempts are made to attribute differences in growth performance among countries to endogenous factors such as investment in human capital, learning by doing, scale economics, and technical change. The contribution of externalities resulting from linked capital and knowledge accumulation, the accumulation of human capital and a continuing growth in the stock of productive designs are stressed as explanations for economic growth. New growth theories follow the neo-classical tradition in its assumptions regarding optimising behaviour.

Arrow's classical paper (1962) identifies technology as knowledge. Knowledge has intrinsic problems of risks, indivisibility and inappropriability which cause firms to under-invest in R&D[11]. Arrow showed that in the case of R&D and technological development the market fails [Smith, 1995]. Neo-classical economists acknowledge that if markets fail – the assumptions of perfect competition are not met –, government may intervene to correct this failure. Correcting for market failure is the traditional rationale for government to stimulate R&D and technological development [Van der Steen, 1999; Smith, 1995; Van Dijk and van Hulst, 1988; Jaffe et al., 2000]. The neo-classical approach accords very well with the traditional linear model of innovation (invention – innovation – diffusion, see Section 2.2) [Smith, 1995].

**Key-points: Neo-classical economic approach**

**1. Technological development:**
- Technological development is exogenous.
- Technology is a black box.
- Technology is knowledge.

**2. Directing technological development:**
- Rational actors maximise the production function.

**3. Government intervention:**
- Corrects for under-investment (stimulates fundamental R&D, supports universities).
- Avoids spill-over e.g. by patent systems to protect accessibility of knowledge.
- Avoids market imperfection, e.g. antitrust laws.
- Avoids information asymmetries by providing information.

## Evolutionary economic approach

Rosenberg's suggestion (1982) that the inside of the black box should be inspected was taken seriously by the school of evolutionary economists. Within this approach, technological development is understood as a path-dependent process of variation and selection.

This approach started to treat technological development as an endogenous factor. The behaviour of innovative firms and the role of technology were studied. Not all firms turned out to have the same source of knowledge, skills, experiences and resources to actually develop or implement innovative technologies. Nelson and Winter (1977) were opposed to the idea that the development of technologies can be understood in terms of a cost-benefit calculation in which the expected pay-offs are simply compared to the estimated costs. The basic tenet is that firms are confronted

[11] There are a number of econometric studies (see e.g. [Mansfeld, 1977; Mansfeld et al., 1991; Grilgriches, 1995]), which assess the private and social rate of return of R&D. Positive and sometimes impressively large rates of return are suggested ranging from 10 to 100%. Such econometric analyses supports the notion that firms tend to under-invest in R&D [Jones and Williams, 1997].

with uncertainty and this cannot be ignored; uncertainty has a large influence on technological development. Firms do not know beforehand which technology will be successful and they are unable to check all technological alternatives. Therefore, their behaviour cannot be understood as maximisation in traditional economic terms. Because of the uncertainty, different firms will disagree about whether and when to invest in R&D [Nelson and Winter, 1977].

In order to deal with uncertainties, firms tend to innovate along certain familiar and known paths. Accordingly, Nelson and Winter (1982) stated that firms apply heuristic search routines. The search routines establish the dominant search directions and guide the occurrence of technological trajectories. The generated variation is path dependent. Technological development is therefore not generated at random but stems from a certain cognitive frame of reference. This frame of reference is shared among a larger number of firms e.g. firms in a specific industrial sector. Nelson and Winter (1977) name this frame as a technological regime, Dosi (1982) as a technological paradigm, and Sahal (1985) as a technological guidepost. The existence of a technological paradigm and thus the occurrence of a technological trajectory leads to the exclusion of other developments [Dosi, 1982].

Influenced by the search routines, firms produce new variations, which may or may not succeed in a selection environment. Nelson and Winter (1977) already stressed that the selection environment comprises not only the neo-classical market concept (such as supply and demand, and prices), but also institutional structures (such as regulation and geographical factors). They chose selection environment above market to emphasise the institutions involved. Institutional structures vary significantly among economic sectors [Nelson and Winter, 1977].

Path dependency, variation and selection are central to the process of technological development. David (1986) and Arthur (1988) further elaborated upon the concept of path dependency. They pointed to the occurrence of non-optimal outcomes due to irreversibility and lock-in. Path dependency and increasing-returns-to-adoption showed that the processes of variation and selection do not guarantee convergence to an optimal dominant design. Variation is not generated at random. An innovative technology is not chosen because it is the best, it becomes the best once it has been chosen. This notion of path dependency implies that innovative technologies differ with regard to the degree to which they fit in with the dominant path.

Several authors have that there is a distinction between incremental and radical innovative technologies[12]. Incremental technologies follow the existing path, whereas radical innovations deviate from the dominant direction of development.

**Key-points: Evolutionary economic approach**

**1. Technological development:**
- Technological development is a path-dependent process of variation and selection.
- Technology evolves from a (firm's) knowledge base.

**2. Directing technological development:**
- Bounded rationality and uncertainty: tending to innovate along known directions.
- Cognitive search heuristics: existing paradigm favours path dependency and lock-in.

**3. Government intervention:**
- Generates variation within an entrepreneurial climate that enhances innovation.
- Formulates selection requirements.
- Broadens the selection environment.
- Establishes feedback between variation and selection in niches or nexus.
- Avoids lock-in to undesired trajectories.

[12] The notion that there are different kinds of innovation has been an important theme in literature since Schumpeter. Abernathy and Clark (1985) make a distinction based on two dimensions, a competence dimension and a market/customer dimension. Innovations may conserve or disrupt the existing technological and production competencies and the markets and customer needs. Tushman and Nadler (1986) make a distinction between incremental changes, synthetic changes and discontinuous changes. The first simply adds features to existing products or processes. Synthetic changes involve a combination of existing ideas or technologies in ways that create significantly new products or processes. Discontinuous changes involve the development of significantly new products or processes. Tushman and Anderson (1986) make a distinction between competence-enhancing and competence-destroying innovations based upon the existing know-how for a certain product or process. An enhancing innovation can be more or less radical in the degree of performance improvement. A competence-destroying innovation is so fundamentally different from previously dominant technologies that the skills and knowledge base required for manufacturing and operating the core technology shift. Freeman and Perez (1988) make a distinction between incremental innovations, radical innovations, changes of the 'technology system', and changes in the 'techno-economic paradigm'. Incremental innovations occur continuously in any industry or service activity. Incremental innovation is often not the outcome of deliberate R&D, but is the outcome of inventions and improvements suggested by engineers or users ('learning by doing' and 'learning by using'). Radical innovations are discontinuous events and are often the result of deliberate R&D. Radical innovations are unevenly distributed over time and over sectors. Such innovations may cause structural changes, although they are often restricted to a specific sector. Changes of the 'technology system' are far-reaching changes in technology affecting several sectors as well as giving rise to entirely new sectors. Changes in the 'techno-economic paradigm' occur when changes in technology systems are so far reaching in their effects that they have a major impact on the entire economy. Christensen (1997) distinguishes sustaining or disrupting innovations. The distinction is based on the value that customers attribute to the performance of products. Sustaining technologies improve the performance of established products along the dimensions of performance that mainstream customers have historically valued. Disruptive technologies market a new performance that becomes valued.

## Systems of innovation approach

In National Innovation Systems (NIS), technological development is regarded as an iterative learning process, which is characterised by complex and interactive feedback mechanisms and relationships among actors in a specific national institutional context consisting of science, technology, production, policy and demand.

Views in this approach exemplify a national approach as opposed to the firm-oriented evolutionary economic theory. Freeman (1987) defined a national innovation system (NIS) as the network of institutions in public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. The focus on interaction within national systems highlights the importance of institutions and organisation beyond the market [Edquist and Hommen, 1999; Edquist, 1997; Lundvall, 1988; Nelson. 1993].

Learning processes among actors are at the basis of technological development [Lundvall, 1988; Nelson, 1993]. The central idea is that the return-on-investment in knowledge generation is dependent on the way in which this process is organised and embedded in societal and economic systems [Smits, 2000]. Technological development is seen as a social process which evolves most successfully in networks with an intensive interaction between the suppliers and buyers of goods, services, technology and knowledge, including public knowledge infrastructure organisations such as universities and semi-public research institutes [Edquist, 1997].

Originally, the national system was studied, but later the level of analysis showed more variation [OECD, 1999]. Some investigators studied regional systems of innovation (see [Grabher, 1993; Oerlemans, 1996]), others preferred technological systems (see e.g. [Carlsson and Stankiewicz, 1991] or clusters of industrial activity (see e.g. [OECD, 1999]).

**Key-points: Systems of innovation approach**

**1. Technological development:**
- Technological development is a process of interactive learning.
- Technological development includes not only R&D and knowledge production, but also the transfer, exchange, and use of knowledge and the demand for knowledge.

**2. Directing technological development:**
- The direction of technological change is not studied explicitly. The aim is to optimise the use of knowledge generation by a system of related and linked actors.

**3. Government intervention:**
- Maintains the institutional knowledge infrastructure of universities and research institutes.
- Stimulates interactive learning among the variety of actors present in the NIS.
- Monitors the NIS by institutional mapping in order to improve the system's overall performance.
- Creates complementary links between public and private actors in order to optimise the use of the knowledge produced. Creates and facilitates access to knowledge.
- Matches the supply and demand for knowledge within the system.

### Industrial network approach

Within the industrial network approach, technological development is seen as the result of interacting (economic) actors. Technological development takes place in the realm of economic relationships that belong to 'neither market nor hierarchy'. A firm never innovates in isolation. Actors are embedded in networks.

Industrial networks are seen as a special form of economic organisation between markets and hierarchies (see e.g. [Williamson, 1985; Powell, 1988; Håkansson and Snehota, 1995]). Networks serve as a co-ordinating mechanism. Economic actors are bound and linked to other (economic) actors in many ways. There are informal links between equal and partially interdependent actors. Network actors are socially embedded through exchange relationships. An actor maintains networks in order to create direct and indirect access to critical resources that it does not possess itself. Although networks can be based on legal contracts, their stability is derived mainly from the establishment of trust, reliability, reputation and customary rules with which members of the network comply. Networks are conceptualised as an important mechanism for creating and accessing tacit knowledge. Networks have a constraining and enabling function to important external resources [Oerlemans, 1996]

The network literature deals in various ways with themes such as learning and innovation (see e.g. [Håkansson, 1987; Porter, 1990; Lundgren, 1995; Håkansson and Snehota, 1995; Oerlemans, 1996]). Håkansson (1987), for example, linked his organisational focus on firms to an industrial network perspective. Actors possess and use resources - such as physical, financial and human assets - to perform certain activities. Actors have certain knowledge about what other actors are doing and what kind of resources other actors have at their disposal. Functional interdependence between actors, differences in power among actors, knowledge and experience of actors and the fact that the existing network is the result of previous investments in relationships mean that actors operate in a network mode. The networks contribute to the production of knowledge. Networks contribute to the co-ordination of resources and lead to resource mobilisation. Networks are typically characterised by long-term relationships [Håkansson, 1989]. Networks have come to be understood as important organisational forms that co-ordinate and direct the efforts of actors engaged in technological development.

**Key-points: Industrial network approach**

**1. Technological development:**
- Technological development takes place in a process of interaction between actors (most often firms) who perform activities and have access to different (complementary) resources. Firms are interdependent.
- Technology results from interactions between firms. Technology itself forms a new resource.

**2. Directing technological development:**
- Firms are related to other actors for the purpose of succeeding in technological development; they take notice of other actors' roles and needs in their own R&D activities and efforts in order to pursue technological development.
- Firms are bounded by their dependence on other actors; functional interdependence, power, knowledge, and times
- No explicit attention is given to directing technological development.

**3. Government intervention:**
- Builds and renews local knowledge-intensive networks.
- Stimulates co-operation.

## Approaches rooted in social constructivism

Technological development is regarded as a process of social construction. Pinch and Bijker (1984) were among the first sociologists to analyse in detail the nature of social interactions which underlie technological development. They suggested the social construction of technology approach (SCOT) [Pinch and Bijker, 1984]. According to the SCOT approach, technological artefacts have an interpretative flexibility [Pinch and Bijker, 1984; Bijker, 1990]. Different actors give different interpretations of the same artefacts and, therefore, have different problem definitions. The interpretative flexibility remains as long as none of the interpretations becomes dominant. The idea is that closure of the various interpretations, i.e. the different meanings stabilise around one interpretation, leads to innovation. All kinds of processes like negotiation, rhetoric and enrolment play a role in this process. Although a particular frame can become dominant, not all actors or constellations of actors need to be equally involved in this frame. There may be different degrees of inclusion. Actors with a high inclusion will focus on solving problems by incremental improvements, whereas actors with a low inclusion in a technological frame are more often the ones who introduce radically different solutions.

According to the actor-network approach every form of change, including technological development, is a change in actor-networks [Callon, 1987]. Actor-networks comprise heterogeneous entities in which the technical is not clearly separated from the social, the cultural or the economic. There is no a priori difference between human and non-human social actors. Actors enrol and translate other actors, values, and interests in such a way that links between different actors are established, strengthened or broken [Callon and Law, 1982]. The translator or prime mover is the dominant actor causing the dynamics in the actor-network. Through mobilisation of other entities in the actor-network this translator tries to solve a specific problem. The selection of a specific solution is the result of the consensus among the relevant actors with regard to problems and solutions. A certain configuration results. The robustness of this configuration can be explained by a detailed description of the mechanisms by which it was constructed.

In Callon's recent work on techno-economic networks (TEN), the emergence, patterns and dynamics of networks are the central issue [Callon et al., 1992]. Whereas Callon focused earlier on the elementary interaction between actors, he now assigns a central role to materialised descriptions. These materialised descriptions or intermediaries such as certain statements, acts and artefacts can be ‘read’ by other actors. Other actors interpret these intermediaries. Their interpretation makes them act or respond in a certain way. TENs are about circulating intermediaries that align and aggregate actors in their activities. A TEN is defined as a co-ordinated set of heterogeneous actors. The actors are organised by three main poles: the scientific, the technical and the market pole. Callon distinguishes three characteristics that constitute the strength and orientation of the techno-economic network, i.e. its completeness, its integration and its length. Technological development is highly contingent. De Laat (1996) used Callon’s approach to develop a socio-technical management tool that research agencies can use to explore several scripts for the future.

**Key-points: Approaches rooted in social constructivism**

**1. Technological development:**
- Technological development is a social process of contingent enrolment and negotiation. Heterogeneous actors are translated.
- Technology has a flexible meaning. Intermediaries of technology align other actors.

**2. Directing technological development:**
- Visions (and stakes) of the interest groups / actors.
- Structure of the techno-economic network

**3. Government intervention:**
- Articulates a specific meaning in the process of negotiation.
- Changes the existing network into a ‘desired’ network; constructs networks, makes them evolve and ensures that they function in a satisfactory manner.
- Network information can be used as an indicator for mapping the status of a technology; changes in networks reflect changes in the status of the technology and can be used for monitoring technological development.

## Quasi-evolutionary approach

In this approach technological development is seen as a co-evolving process of actors and technology within a certain regime. Regimes are outcomes of earlier changes and they pre-structure subsequent technological developments.

The quasi-evolutionary approach is a sociological version of evolutionary economic theory. Key concepts such as variation and selection formed the starting point, although their meaning was gradually refined. Authors like Belt and Rip (1987) started by stressing the social context in which economic agents are embedded. The agents generate variations. In doing this they anticipate to the expected selection environment. This linkage of variation and selection occurs e.g. in a nexus, an institution or department which carries and shapes the interaction between societal and market requirements and technological opportunities. Actors with a vested interest, and often also with a high reputation in a technological field may protect their interest by actively participating in certain developments [Belt and Rip, 1987; Schot, 1991]. Actors operate strategically in aligning the technology within the context in which it is being developed and applied [Rip, 1995].

In quasi-evolutionary theories, the influence of the context in which technological development occurs is conceptualised as the technological regime. The regime comprises not only the cognitive aspects of the problem-solving activities of engineers (the set of search heuristics), but also the wider economic and other social conditions, like the existing technological infrastructures, the rules of the market in which actors operate, existing networks of business relations, and economic factors [Rip and Kemp, 1998; Van der Poel, 1998]. A technological regime contains rules that facilitate and constrain actors' activities. They guide actors in the decisions they take. The rules guide - but do not fix - the direction of technological development [Kemp et al., 1998]. The rules are shared resulting in certain patterns of technological development. Innovative technologies are always introduced against the backdrop of existing regimes. Micro-level actors have to discover whether the innovative technology fits in with the existing regime [Rip and Kemp, 1998].

Van Lente (1993) introduced the idea of promises and expectations as one of orienting elements in technological development [Lente, 1993]. When expectations are shared by many actors, they will dominate the agenda of activities and set the rate and direction of technological development [Schaeffer, 1998; Lente, 1993]. Promises and expectations legitimate choices in R&D activities, they mobilise attention and financial support and they finally reduce the uncertainty inherent in technological development. Actors therefore use expectations in their R&D activities, and in their turn, promises and expectations guide actors in their decision-making processes. Expectations contain a script for the future that guides R&D activities[13] [van Lente, 1993].

The quasi-evolutionary approach recognises the occurrence of inter-linked processes at the micro, meso and macro level [Rip and Kemp, 1998; Lente, 1993]. The concept of regime understands cumulative and patterned nature of technological development. It explains why technological development is to a certain extent non-malleable and why it is difficult to orient technological development [Rip and Kemp,

[13] A well-known example of a promise operating as a script is Moore's Law. Moore's Law has become a self-fulfilling prophecy. All micro-processor firms tune their R&D activities to obey this law because they know their competitors also do. The prophecy of the law is that actors start acting accordingly.

1998]. One of the intervention options that may help to orient technological development is strategic niche management [Kemp et al., 1998]. The idea is to create temporary protected spaces – market or technological niches –. They function as a local breeding space through which social learning among actors occurs. Niches protect variations (and the expectations linked to it) against too rapid and harsh selection.

**Key-points: Quasi-evolutionary approach**

**1. Technological development:**
- Technological development is a process of co-evolution at different levels of analysis (micro, meso, macro).
- Technology is an object in a co-evolutionary learning process. The result may be a technology that fits in with the existing regime or that gives rise to a new regime.

**2. Directing technological development:**
- The technological regime: rules guide – but do not fix - actors' R&D activities.
- Shared promised and expectations.

**3. Government intervention:**
- Changes the rules in a regime.
- Facilitates learning processes among actors.
- Establishes niches of protected learning (link variation and selection).
- Develops socio-technical scenarios for the future.

## Large Technical Systems

In this approach, technological development is regarded as the transformation of technical systems. The study of the unique evolution and transformation of large technical systems such as energy supply, telecommunications or transport from a historical perspective has shown that technological interdependencies and momentum can be both strong determinants of and constraints on future technological pathways.

The historical approaches are inspired to a large extent by the work of Hughes [Hughes, 1983; Hughes, 1987]. His system approach considers technological development as the development and growth of a system of heterogeneous (technical, social, juridical, geographical) components. These heterogeneous components are so closely interlinked that it is often hard to make a distinction between them. The components constitute a seamless web. The nature of the technical systems goes beyond the interrelated physical artefacts.

There is an inherent logic in the technical system that sets the direction for technological development; the entire system is expanded so that the entire system is used optimally. The expansion of a system is not regular. Components which hinder the growth of the whole system are called reverse salients. These reverse salients can rise due to internal (inside the boundaries of the system) or external (outside the boundaries of the system) factors. The reverse salients are the essence of the creative process. System builders, leaders or promoters of the system, who are typically technical professionals with excellent entrepreneurial competencies, translate these reverse salients into critical problems. Above a certain size, a socio-technical system acquires its own dynamic, its own momentum. As it is growing a system develops more and more momentum, which makes it appear as if it is developing autonomously. The other side of the coin is that this so-called momentum may result in system inertia. The technical system is strongly entrenched as a result of the investments in capital, the way actors involved are organised and the knowledge practices which commonly operate within that system.

**Key-points: Large Technical Systems**

**1. Technological development:**
- Process of solving critical problems to optimise performance of a technical system.
- Technology is part of an (expanding) technical system.

**2. Directing technological development:**
- Inherent in the technical system; reverse salients - critical problems - occur. They have to be solved to expand the entire technical system.

**3. Government intervention:**
- Causes or strengthens existing and slumbering reverse salients.
- Reinforces the capacities or possibilities of system builders.

## 2.5. Towards a framework

### Triangle of technological development

At the beginning of this chapter it was suggested that the process by which a specific industrial energy-efficient technology develops could be characterised in terms of actors, networks, and the role of government. The various approaches used in technology studies provide us with valuable insights and with suggestions about what to look for in the empirical research. Instead of opting for one specific approach we select aspects of several approaches since they are largely complementary. Whereas there are clear differences between the approaches in their specific theoretical focus (and in the terminology used), the approaches converge, enabling us to obtain a broad and realistic understanding of technology and technological development [Rip and Kemp, 1998]. We are interested in obtaining some guidelines for the performance of the technology case studies.

Common to all the approaches is the idea that technological development can be conceptualised as a social process in which ‘Artefacts’, ‘Actors’ and ‘Agenda’ are constructed and interact. These triple As are summarised as the triangle of technological development (see Figure 1) [Van Lente, 1993; Schaeffer, 1998].

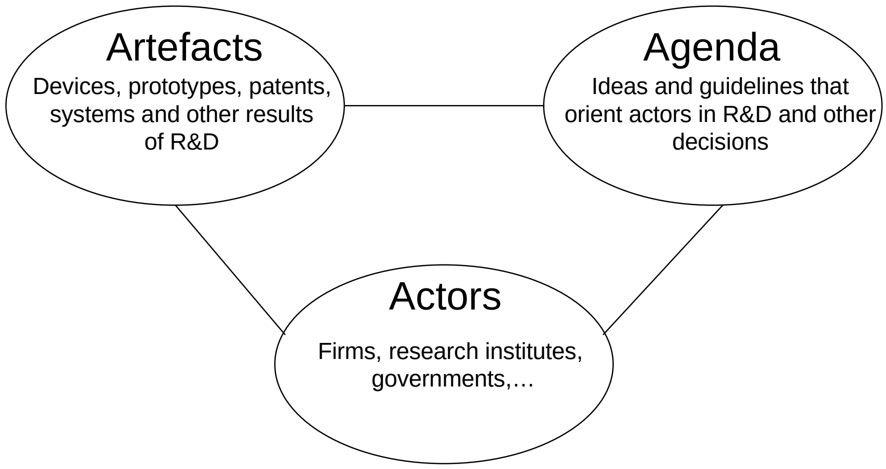


*Figure 1: The triangle of technological development.*

The triangle provides us with a heuristic tool for summarising how scholars engaged in technology studies understand technological development. All approaches frame their analyses in terms of actors and in terms of interactions and networks. The actors interact on the basis of their specific resources and capacities. They make statements and claims, apply for patents, produce and communicate R&D results, prototypes, and other types of artefacts. This social process in which technologies are shaped is guided by elements that orient actors by giving priority and direction to their R&D activities [Kingdom, 1984; Van Lente, 1993].

With this heuristic tool in mind we elaborate upon the three key-points that we used to summarise each of the approaches in Section 2.4. The discussion below gives a more detailed sketch of how technology studies interpret technological development in terms of actors, artefacts and agenda. This leads to a preliminary list of questions and remarks that can prove useful to arrive at a framework for empirical research.

### Technological development and innovative technology

All approaches share the view that innovative technology cannot be described in technical terms solely. They reject the linear and sequential model of technological development and refute the suggestion that the technologically optimal solution will result automatically. Technology does not exist as independent artefact with fixed characteristics which enters the economy at a precise point in time. Instead, technology involves economic, technical and social elements, all of which are highly intertwined. Technology is seen as a 'configuration that works'; it comprehends the technical hardware and its underlying principles (as e.g. skills, knowledge, experience and routines) necessary to install and operate the hardware and to use it productively in a certain context (derived from [Rip and Kemp, 1998]). Every piece of technology is thus embedded in a specific context that is constituted by other technologies and a constellation of actors who know how to exploit these technologies. In technology studies, scholars are very wary about separating the technical side (the artefact), from the social side (the actors and the way actors and artefacts are embedded). Scholars prefer to use terms such as socio-technical changes or socio-technical outcomes.

Technological development is thus seen as a process of a social nature. No results are achieved unless *actors* are willing to invest in or undertake R&D activities. Actors are the vehicles that bring about technological development and innovation. Actors are interdependent. Networks have become the key-concept that links actors. Actors have a certain stake in new developments, and have certain capacities or resources. They perform R&D activities, interact and co-operate, try to mobilise other actors, and articulate performance claims and expectations with regard to their R&D activities. Through network interactions tacit knowledge[14] and experience are exchanged, the opportunities and needs for improved technologies are matched, and promises and expectations are articulated.

In short, innovative technology is seen as the outcome of a social process. In our search to obtain guidelines for the performance of the technology case studies, the following questions can be listed:

- Which actors are involved in developing an innovative technology? What kind of actors are they (firms, universities or research institutes)?
- What are the actors' interests or stakes for being involved? What task or role do they have in developing the energy-efficient technology?
- How are actors embedded in the socio-technical networks of a manufacturing industry and what is their reputation?
- What are actors' resources and capacities? Do they have adequate finance, equipment and research facilities, and experience in conducting R&D?
- In what countries are the actors operating? How many different R&D efforts can be distinguished?
- Do actors co-operate? Who interacts with whom? And why? How important is co-operation in delivering R&D results?
- Is there any other kind of exchange and communication between actors? What do they exchange? In what way? Why?
- Are some actors more dominant than other actors during the development of an innovative technology?
- What steps are taken in developing an innovative technology? How long does it take to develop the technology? What explains this time-frame?

[14] Tacit knowledge is considered to be a crucial aspect of technological development. Polanyi (1966), who claimed that the only way to transfer tacit knowledge is through social interaction, suggested the concept. Dosi et al. (1988) suggested that *"Tacitness refers to those elements of knowledge, insight and so on, that individuals have which are ill-defined, uncodified and unpublished, which they themselves cannot fully express and which differ form person to person, but which may to some significant degree be shared by collaborators and colleagues who have a common experience" [Dosi et al., 1988, p. 1126]*.

- What results from R&D activities? What kind of claims and expectations are articulated?

## Guiding and directing technological development

Technology does not develop in a random manner. Actors are guided in their R&D activities and decisions by the context in which they operate. Frames or regimes direct acting. The frames are typically shared by a larger number of actors. This contextual structure brings regularity into technological development. It pre-structures the ideas and notions about where to look for further technological development and problem-solving activities. Processes of technological development are embedded in what is believed to be a fruitful direction for progress. The frames make technological development cumulative and non-malleable and make technological development difficult to orient. If a large number of actors are looking in the same direction and if there are strict rules which make these actors look in that direction, it is not very easy to change the direction of technological development. A certain path dependency occurs. Note that such structuring regimes or frames are, however, an outcome of earlier social activities. This illustrates that the distinction between 'structure' and 'action', as often made in classical (sociological) discussions, may be considered as two sides of the same coin. Structure is produced by action, but at the same time it organises action [Rip and Kemp, 1998; Schaeffer, 1998; Van der Poel, 1998; Van Lente, 1993].

In our search on how to characterise the process by which specific industrial energy-efficient technology develop, we come up with the following questions:

- What are actors' arguments for being interested in the innovative technology? Why do actors attach importance to these arguments?
- What are the most promising performance characteristics of the innovative technology? What implications does an innovative technology have for a manufacturing industry?
- What influences actors' decisions with regards to R&D? What guides actors to prefer certain directions of technological development?
- Why do actors continue R&D activities? And, possibly, why do they terminate these activities?
- Why does an innovative technology emerge at a certain moment in time? How does the technology relate to the context in which it is to be applied?

## Government intervention

Government intervention is part of the 'black box' that has to be studied in itself [Van der Steen, 1999; Rip and Kemp, 1998]. Government is one of the actors that may induce other actors to undertake R&D activities. The various approaches adopted in technology studies give rise to a new perception of the role and possibilities of government in stimulating R&D activities and directing technological development[15]. Technological development is seen as a learning process of interacting actors. Government should take into account the dynamics in existing networks. Table 1 illustrates the consequences of technology studies for government intervention[16].

*Table 1: Role of government in stimulating technological development*

| **Dimensions** | **Traditional way of looking at government intervention in technological development** | **System or network way of looking at government intervention** |
|---|---|---|
| Scope of analysis | Relation government - firm | Networks of firms |
| Perspective on role government | Central steering role of government – static | Government is an actor among actors – dynamic |
| Type of relations | Hierarchic | Interdependent |
| Perception of steering | Implementing policy instruments for achieving goals | Facilitating the learning processes |
| Focus | Push – linear model | Push and pull – systemic model |
| Selection instrument | Independent from steering context / network | Depending on steering context / network |

Government cannot control the outcome of the social process of technological development. The role of government needs to be evaluated as part of the network and compared with the role of other incentives, decisions and dynamics. We require answers to the following questions:

- Did government play a role in developing an energy-efficient technology? If yes, in what way?
- Did government affect the R&D decisions taken by the other actors? If yes, in what way? If not, why not?
- What would have happened had there been no government intervention taking into account information about the role of actors and dynamics in technological development?

[15] See also Section 2.3.
[16] The traditional (neo-classical) rationale for government intervention is to correct market failure. In this set-up the basic policy task is to encourage discovery-oriented activities, and then to protect the use of the results. The approaches adopted in technology studies suggest a broader rationale for government intervention in R&D and technological development. The insights have induced a so-called 'rationale of systemic imperfection' [OECD, 1999; OECD, 1998; Van der Steen, 1999]. Government intervention should focus on preventing imperfections in the systems or in the networks of technological development and innovation. It can do this by establishing interaction among actors where it is missing, by providing information, by increasing access to knowledge, by matching need for knowledge with knowledge supply, creating demanding customers, and by organising participatory decision making processes about strategic areas of R&D and technological development and by creating future images of society. The role of government is increasingly portrayed as that of a facilitator, broker, game-manager, cluster, network-builder or niche-manager [Edquist and Hommen, 1999; OECD, 1999; Rip and Kemp, 1998].

### A network-oriented framework

Networks of actors are the key feature of our framework; we therefore also refer to a network-oriented framework. In the development of the energy-efficient technology not all actors have an equally close relationship. Therefore, we distinguish a micro-level of activities – the micro-networks –, and a meso-level which includes the entire constellation of actors active in developing a specific technology. This total set of micro-networks we define as the technology network. A micro-network consists of one actor or a small group of actors who co-operate in developing a specific industrial energy-efficient technology. They co-operate on the basis of specific skills or financial resources, they perform R&D activities, test materials and build prototypes, etc. The actors in the micro-networks learn from their own R&D results, learn from each others' experience, but they commonly also look at what other micro-networks are doing. The innovative technology, or a specific version of the innovative technology, materialises within the micro-networks. The actors are embedded in a context, also called the innovation background, which influences actors' ideas and perceptions of what is believed to be an interesting direction for progress. It guides actors' R&D agendas. Elements in the innovation background are for instance the market in which the firms operate, existing business relationships within and between industrial sectors, sector developments, and the existing production process for manufacturing steel or paper.

Figure 2 shows the framework of micro-networks, the technology network and the innovation background.

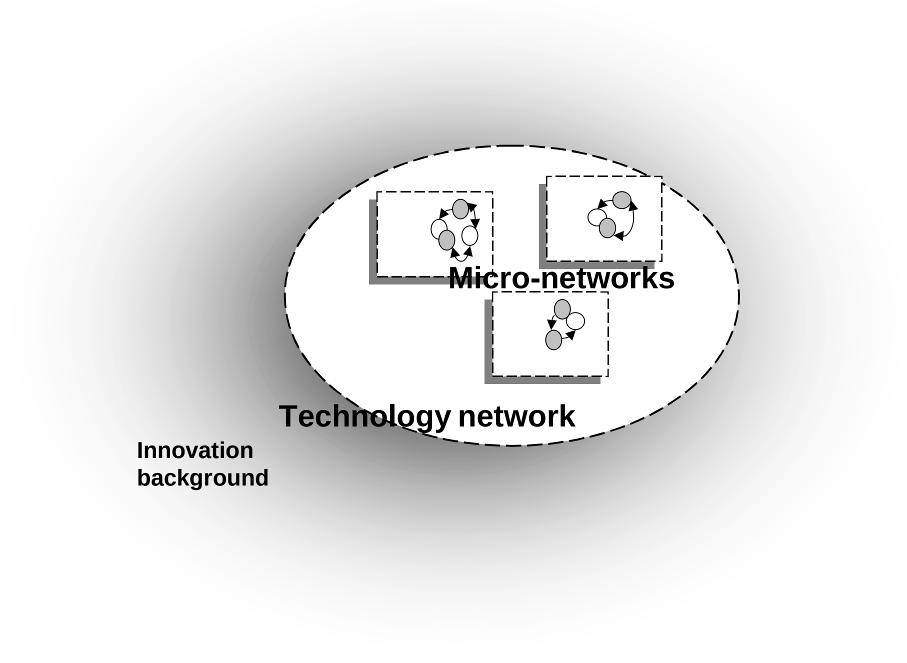


*Figure 2: The network-oriented framework to analyse the development of industrial energy-efficient process technologies.*

Note that the three elements distinguished in the triangle of technological development are all present in this network-oriented framework. The framework provides us with a structure for understanding who is involved and who interacts with whom – Actors –; for realising what guides R&D and technological development by understanding actors' arguments for developing a specific technology – Agenda –; and for mapping what results from all these R&D activities and showing how these affect further technological development – Artefacts –.

Now we come to the case study questions that guide us in performing and analysing the empirical case studies. We formulate questions about the technology network, the micro-networks and the materialisation of the technology. Government is one of the actors that may play a role in developing the technology. As indicated before, in each of the case studies government's role is evaluated as part of the specific case study. The effect of government intervention is analysed explicitly. Table 2 gives an overview of the questions.

*Table 2: Case study questions.*

| **Research foci** | **Triangle** | **Underlying questions** |
|---|---|---|
| Technology Network | How does the collective network of the micro-networks develop? | 1. What is the composition of the technology network? How many micro-networks can be distinguished? What is their geographic distribution?<br>2. What are the links between micro-networks? To what extent and how often do micro-networks exchange knowledge/information?<br>3. Are there dominant micro-networks in the technology network? |
| Micro-Network | Who are the actors involved and what is their agenda? | 1. How are the various micro-networks made up? Who and what type of actors are involved?<br>2. What motivates actors to start and / or stop R&D activities?<br>3. How much money is spent and by whom?<br>4. What important decisions are made with regard to the direction of the technological development? |
| Materialisation of the technology | What are the results of the R&D activities undertaken? | 1. What is the rate of development and what steps in up-scaling can be distinguished?<br>2. What are the perceived performance characteristics of the technology (including the technological interrelatedness with the existing technological system)? |
| | | |
| Government | What was the effect of government intervention? | On the basis of the description and analysis of the technology case study, the role and effect of government intervention can be evaluated specifically with regard to:<br>- additionality<br>- acceleration<br>- effectiveness |

We do not pose explicit questions about the innovation background, because it is reflected in the considerations and decisions taken by actors within the various

micro-networks. If we want to understand actors' arguments we need to include how actors are embedded in a particular context.
The materialisation of the technology is explicitly considered by focusing on the steps take to up-scale the R&D equipment and by asking for the perceived performance characteristics of the innovative technology. We have three reasons for explicitly looking at artefacts. First of all, it increases our understanding of why things happened as they did. Artefacts such as research equipment or patents are an important resource for actors. Steps in up-scaling are often occasions for contacting other actors in order to establish co-operation or mobilise financial resources. Secondly, actors involved in developing the specific technology use statements about a technology's perceived performance for mobilising R&D resources and external R&D support. Explicit consideration of such claims about the technology's performance and a proper understanding of the role of such data in the social process of technological development are important indicators with regard to the possible role that government can play. And thirdly, the materialisation of the technology captures the characteristics in which energy analysts are traditionally interested. By discussing these characteristics separately we can study how important these other indicators are in order to understand the process of technological development.

The network-oriented framework and the set of questions are generic and open in nature. We use them as a checklist for data gathering and in organising data analysis (see also Section 1.6). They are not directed towards the testing of a (theory-driven) hypothesis. The framework and questions are meant to force the analyst to look at all the elements of technological development that are relevant for the central research question and to compile a comprehensive and coherent history of each specific technology case study. However, a standard recipe for success is not provided. Carrying out the technology case studies requires thorough research, critical questioning, careful data analysis and a mind-set involving 'understanding-by-performing'.

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# Chapter 3

# Shoe press technology


## Abstract

*Shoe press technology is a paper-making technology that improves dewatering of the board or paper sheet in the wet pressing section and, therefore, reduces the need for evaporating drying. In this case study, we evaluate the importance of internal factors - actor characteristics - and external factors - the way in which these actors are embedded in a specific context - on the development and diffusion of shoe press technology.*

*Developing the technology took about 13 years (1967-1980). The technology network consisted of one micro-network and for a long time even of one firm. Although the idea for extending pressing time was acknowledged by others, only the people at the US machine supplier Beloit continued to believe that such a major new press design could be engineered. A fabric supplier was involved to suggest a suitable belt at the moment that the first commercial shoe press for a board machine had already been sold. The fabric supplier succeeded in time. Without the belt, innovation (1980) would have been delayed. Only by then, three other machine suppliers started R&D activities. They developed improved shoe press designs with a 'closed' belt.*

*The major argument for developing shoe press technology was to increase the machine capacity of existing board machines and to reduce the capital intensity of new board machines. During the early eighties, machine suppliers claimed advantages for other paper grades too. Only when conventional wet presses limited a further increase of machine speeds the shoe press became a proven technology in paper machines too (from 1994 onwards).*

*A first conclusion is that actor characteristics were decisive for the successful development of shoe press technology. Note that Beloit's success did not occur in a vacuum. There was a wider acknowledgement of the importance of extending time in wet pressing. Furthermore, Beloit had a 'proven' reputation as one of the world-wide major machine suppliers. A second conclusion is that external factors were decisive for ongoing improvements from 1980 onwards. Further R&D activities were driven by the market success of shoe press technology.*

## 3.1. Introduction

Ongoing development of innovative technology can be regarded as an important way of reducing emissions that give rise to the enhanced greenhouse effect [IPCC, 1996; UN, 1997]. In this regard, energy-efficiency improvements in the manufacturing industry have been indicated as an interesting field for government to stimulate the development of innovative technologies (see e.g. [De Beer, 1998; Blok et al., 1995]). If governments want to stimulate technological development effectively, they must have a thorough understanding of what drives the development of energy-efficient technology. In this chapter, we analyse the process by which a successfully introduced energy-efficient technology developed. We want to understand which factors drove the development of a specific energy-efficient technology.

Research performed in the interdisciplinary field of technology studies claims that technological development needs to be understood in terms of networks. Firms hardly ever innovate in isolation [Edquist and Hommen, 1999; Rip and Kemp, 1998]. Authors of network-oriented studies try to understand technological development by making a distinction between the characteristics of the actors, 'internal factors', and the way in which these actors are linked to each other and embedded in a specific context, 'external factors'.

As a case study we selected shoe press technology, which is considered to be a successfully introduced energy-efficient process technology (see e.g. [De Beer et al., 1994; Martin et al., 2000]). Since its introduction in 1980, this technology has improved the energy efficiency of the pulp and paper industry. Shoe press technology has been one of the major innovations in paper making in the 20th century [Mirsberger, 1992b; Wedel, 1993; Lockie, 1998]. With regard to this case study we address two questions:

1. What was the balance between internal and external factors, which drove the development of shoe press technology?
2. What is the balance between internal and external factors, which has driven the further improvement of shoe press technology since the moment of innovation?

In Section 3.2, we briefly introduce the pulp and paper industry, the paper production process and shoe press technology. In Section 3.3, the historical development of shoe press technology is mapped up to the moment when the first shoe press was installed. In Section 3.4, we map the R&D developments that have taken place since the moment of innovation. In mapping the history of shoe press technology we present elements that return in our analysis of the case study in Section 3.5. A short discussion of the validity of the analysis is given in Section 3.6. The chapter closes with some conclusions.

## 3.2. The sector, the production process and shoe press technology

### Pulp and paper industry

The pulp and paper industry is a capital-intensive industry that manufactures commodity products. The competition in the sector is based on price and on economics of scale. The added value of the majority of the products is low. The demand for paper increases slowly and steadily (with some temporary setbacks), still the paper industry is faced with cyclical fluctuations in the prices of their products. This clyclicality is caused by the supply of new paper machine capacity at times aggravated by the sensitivity of the paper industry for general business cycles. The price elasticity of paper is low. Over-capacity and sudden increases in paper capacity put pressure on market prices. The industry is increasingly consolidating. Mergers and acquisitions are expected to continue. All in all, a continuous operation of the paper machine is what keeps a paper firm in business. The industry is focused on proven technology that can increase paper machines' production capacity. Since paper making has become a continuous operation, the history of technological development has been one of solving critical bottlenecks in the paper machine for making them wider and faster [Luiten, 1997].

### Making paper or board

Making paper or board[1] involves three clusters of activities; furnish preparation, the paper machine and finishing operations. In the preparation of furnish, pulped wood and/or waste paper is processed and mixed with water, some chemicals and other additives. This mixture is called furnish. The percentage of dry solids in the furnish, also called the dryness of the paper sheet, is about 1%. Then, the furnish is fed into the paper or board machine. Water is removed in three sections; dryness increases as the paper sheet moves along the paper machine:

- Forming section: forming the paper sheet while draining and suctioning (1% to 20% dryness)
- Pressing section: mechanical dewatering by passing the paper sheet through a number of press nips (20% to 45% dryness)
- Drying section: evaporative drying of paper sheet (45% to 90-95% dryness)

[1] Paper is generally used to indicate all the different grades produced by the pulp and paper industry. In this chapter we make a distinction between *printing paper* and *board*. To clarify this distinction we use the term paper machine to indicate a machine that produces printing paper and the term board machine to indicate a machine that produces board grades. *Printing paper* is a collective term for all printable (coated or uncoated) mechanical pulped or wood free papers. It serves as the medium for printed information. It is generally lighter than 150 $g/m^2$. *Board* is used to indicate thick and stiff paper, often consisting of several plies. Board is generally used for packaging purposes. It is normally heavier than 150 $g/m^2$. Packaging paper is a collective term for papers or boards of different pulp compositions and properties sharing only the application [CEPI, 2000].

Finally, finishing operations as e.g. calendaring, winding and cutting are needed to deliver the final product.

The paper machine's drying section requires the largest amount of energy per kilogram water removed. Improvements in the specific energy consumption of a ton of paper are therefore typically directed at reducing the energy requirement of the drying section (see e.g. [De Beer, 1998; Martin et al., 2000]). This can be achieved by improving drying technologies. A second route is to increase the amount of water removed in the pressing section.

### Shoe press technology

Shoe press technology is an exemplary technology of the second category; it improves the dewatering capacity of the conventional pressing section by extending the time that the paper sheet remains in the press nip. This time is also called the nip residence time. The amount of water removed in the pressing section is proportional to the magnitude and the duration of the pressure applied to the paper sheet. The product of pressure and nip residence time is called the 'press impulse' [MacGregor, 1989; Pikulik, 1999].
In conventional roll presses both the pressure applied and the nip residence time were constrained. Pressure could not be increased unlimited, because the paper sheet would be damaged (especially at higher machine speeds). Nip residence time decreased with increasing machine speeds. The constrained press impulse of conventional roll presses was overcome by shoe press technology (see Table 1 and Figure 1).

*Table 1: Design parameters of a conventional roll press and a shoe press (based on [Wahlstrom, 1991; Wedel, 1993]).*

| Design parameters | Roll press | Shoe press |
|---|---|---|
| Length of press or nip width (cm) | 4 – 7 | 25 – 30 |
| Linear load (kN/m) | 150 – 450 | 1,000 – 1,500 |
| Press impulse ($kN*s/m^2$)[1] | 3.0 – 5.0 | 15 – 21 |

[1] Press impulse depends on the speed of the paper or board machine, the length of the press nip and the linear load applied. The data reported in the table are indicative.

The nip of a shoe press consists of a stationary shoe, which is loaded against a press roll (see Figure 2). A stationary, concave shoe press replaces the conventional bottom roll. Felts are required for transporting the water from the press. A belt or sleeve forms the shell that runs between the mechanical press and the bottom felt. Oil is supplied on the inside of the belt to act as a load transfer medium and to provide lubrication between the stationary shoe and the moving belt.

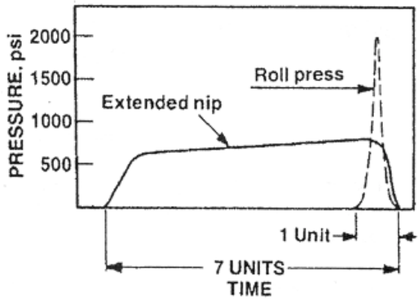


*Figure 1:* *Difference between the pressure profile of a conventional roll press and that of a shoe press. The areas under the curves are the press impulse (1 psi = 6.9 kN/m$^2$).*

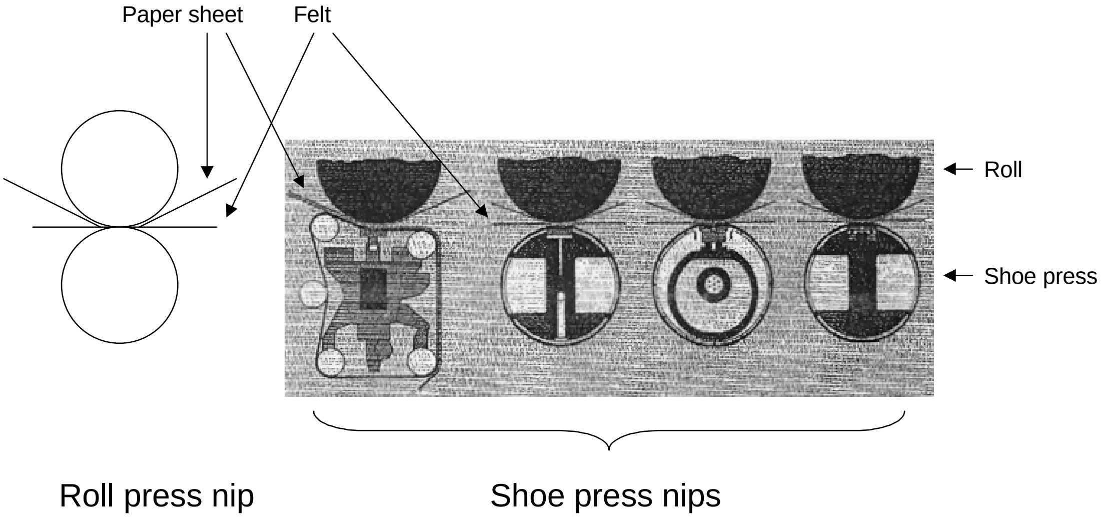


*Figure 2:* *Cross-section of a conventional roll press nip and various shoe press designs. The shoe press on the far left has an open loop belt (Beloit's ENP-O). The other three designs have a closed belt or sleeve (derived from [Schiel, 1992]).*

The major advantage of the shoe press is the higher dryness achieved at the exit of the pressing section. Depending on the grade produced, the increase is about 5 to 10% compared to conventional pressing. This results in a better runnability[2] [Wedel, 1993]. The higher dryness leads to an increased production capacity (about 10 to 20%), when a shoe press is put on an *existing* (dryer limited) paper or board machine. When a shoe press is implemented on a *new* paper machine, the drying section can be shortened thus reducing capital expenditure.

A second advantage is the reduced demand for steam in the drying section. This may lead to an improvement in energy efficiency in spite of the increased electricity consumption. Additional driving capacity and increased pumping capacity for

[2] Runnability is defined as how smoothly paper runs through a paper or board machine or printing press without breaking the sheet [CEPI, 2000].

cleaning the felts are needed. If increased electricity consumption is not taken into account, a shoe press may save 0.5 GJ to 2.0 GJ per ton paper[3]. Savings in energy costs are of the order of 1 to 5 $ per ton paper. Energy cost savings make up 60 to 80% of the payback generated if the machine's speed is not increased. If a paper machine's production speed is increased, energy cost savings make up 10 to 20% of the payback per ton paper[4] [Sirrine, 1982; Anonymous, 2000].
A third advantage is improved product characteristics. The pressing section is important for paper properties because most physical and surface characteristics are in some way related to the density of the sheet. Pressing causes densification [Lange, 1996; Mirsberger, 1992a]. The effect of a shoe press on paper properties differs among the grades produced. Installing a shoe press on a board machine induces a favourable increase in strength properties. This permits savings in refining, the use of fewer strength additives, and the application of cheaper furnishes. The installation of a shoe press on a paper machine leads to a higher dryness without reducing the thickness of the sheet [Wahlstrom, 1991; Mirsberger, 1992a]. This results in cost savings by reducing the amount of fibre needed [Lange, 1996].

## 3.3. Historical development of shoe press technology – before 1980

### Early developments in roll press technology

At the beginning of the 20th century, a woollen felt carried a paper sheet through the pressing section which consisted of two rolls (see Figure 2). The use of two roll presses remained the dominant design until the introduction of the shoe press in 1980.
The original press rolls were solid. The first improvement, which increased the dewatering capacity of the pressing section, was introduced in 1925. By making the bottom roll of the press hollow and providing it with a perforated shell, water could be extracted into this roll by means of a vacuum. This roll press, the suction press, became widely used. When the widths and speeds of paper machines increased, the disadvantages of the suction press became more evident. The vacuum equipment was

[3] De Beer (1998) reports that the specific energy consumption of a ton paper ranges between 9 and 17 GJ / ton (depending on paper grade). Primary energy savings depend on machine-specific factors such as the amount of steam needed to evaporate the water, the increase in dryness realised after the pressing section and the steam generating efficiency. A small survey among Dutch paper firms having a shoe press on one of their machines, made it clear that the payback generated by energy savings is too low to fulfil paper manufacturers' investment criteria. In all cases the investment was justified by the increased production capacity. In one case, steam savings in the dryer section were cancelled out by an increase in electricity use [Anonymous, 2000].
[4] Crucial assumptions have to be made about steam savings, other savings especially in raw materials, energy prices, production increase and the net gross margin on a ton of paper sold.

costly, the power consumption was high and the costs of maintenance such as cleaning the holes in the roll were substantial [Håkanson, 1974].
Researchers at Beloit, a US paper machine supplier, undertook R&D activities in order to reduce the costs of the suction press and to further improve the dewatering capacity [Justus and Cronin, 1964; Justus and Cronin, 1981]. The result was the vented roll press, which had grooves in one of the rolls so that the pressure in the press nip could be increased without crushing the paper[5]. The first vented nip press was installed in the US in 1963. The vented nip press allowed a further increase in pressures applied, so that the dryness at the exit of the pressing section was gradually increased (see e.g. [Håkanson, 1974; Schmitt, 1973; Justus and Cronin, 1964; Lord, 1982]).
The development of the suction press and the vented roll press, as well as the continuing improvements in areas such as press roll covers and press felts, improved water removal in the pressing section. However, nip pressures could not be increased indefinitely. Crushing of the paper, short felt life and short roll cover life limited the potential for increased water removal [Schmitt, 1973; Justus and Cronin, 1981; Wicks, 1983; Cronin et al., 1985].

### New directions in wet pressing R&D – 'press impulse'

Research into wet pressing seriously took off in the sixties. The first studies that provided a fundamental understanding of wet pressing were presented in 1960. Against this background of growing research interest in wet pressing, the idea emerged that optimising dewatering in the pressing section was not simply a matter of pressure, but involved nip residence time as well [Daane, 1973; MacGregor, 1989]. Some illustrative evidence for this can be found.
Wahlstrom and Schiel, for instance, independently suggested the concept of the 'press impulse' at an international wet pressing conference in 1968. Wahlstrom and Schiel, who were both working for firms supplying paper machines, introduced this theoretical concept in connection with optimising water removal for a specific paper sheet in a conventional pressing section [Wahlstrom, 1969; Schiel, 1969; Daane, 1973; Busker and Cronin, 1984; MacGregor, 1989; Schiel et al., 2000]. For reasons of completeness, we mention that Campbell (1947) seems to have been the first reference suggesting that water removal is dependent on press impulse. Campbell's paper was the first paper to cover some fundamental concepts of water removal in the pressing section, though it is largely under-cited in wet pressing R&D [MacGregor, 1989].
A second illustrative example is the research activity of Jahn and Kretzschmar at Pama, an East-German machine supplier. Not much is known about their R&D

[5] Upon entering press nip, the paper sheet may get crushed when the pressure increases rapidly (this problem becomes more acute at higher machine speeds). *Crushing* is the localised disruption of the fibres and fillers in the paper sheet due to the *flow resistance* to the water in the sheet and the rate and pressure at which the water is expelled from the sheet.

activities; only that a patent was issued in 1971[6]. The patent clarifies that they tried to modulate the form of the pressure profile. Some claim that this patent is the first shoe press patent. Others claim that the patent 'only' covers a method to prevent rewetting. However, the main point is that several people were aware of the importance of the press impulse and the form of the pressure profile in wet pressing.

## The development of Beloit's shoe press – the extended nip press

Busker, who worked at Beloit's Rockton lab, also noticed the importance of time in wet pressing [Busker and Cronin, 1984; MacGregor, 1989]. Beloit was a US machine supplier. In December 1967, Busker started research activities that would eventually lead to the development of Beloit's shoe press, the extended nip press (ENP). He developed a mathematical pressing simulation model [Busker, 2000; Cronin et al., 1985]. Justus, manager of Beloit's Rockton lab, stimulated Busker to start research in this direction. Wet pressing was seen as an important machine component, which thus had to be included in Beloit's research programme. No one had any specific ideas about product developments at that time [Busker, 2000; Bergström, 2000].
During the summer of 1968, the pressing simulation model showed clearly that optimising water removal was both a pressure-dependent and time-dependent process. Excitement grew when Busker and others at Beloit started to perceive possible ways of substantially increasing the amount of water removed by 'extending' the nip residence time. Beloit's primary interest was to increase sheet dryness, because this would allow existing (dryer limited) board machines to increase production and new machines to reduce the length of the drying section [Bergström, 2000; Lange, 2000].

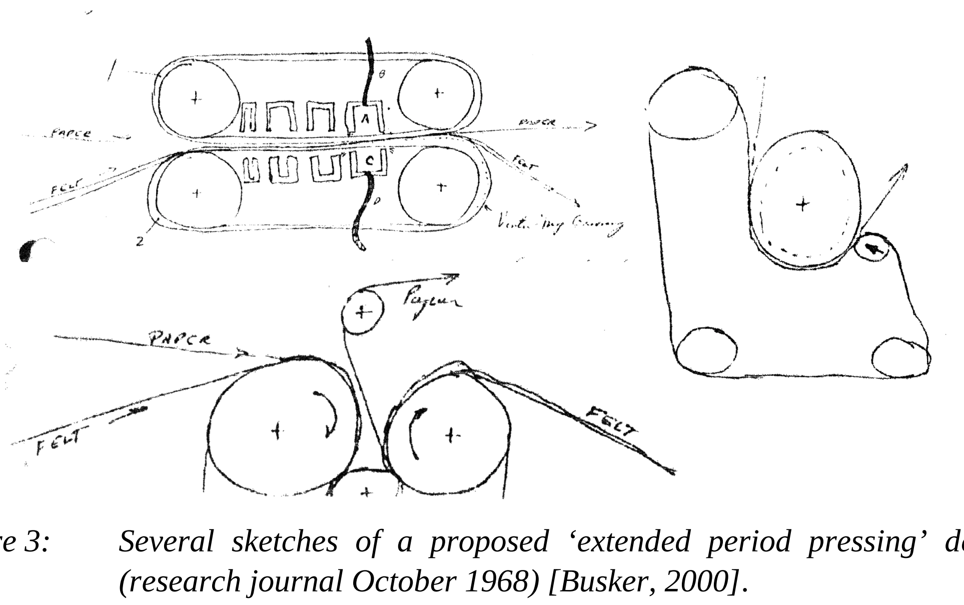


*Figure 3: Several sketches of a proposed 'extended period pressing' device (research journal October 1968) [Busker, 2000].*

[6] Schiel (Voith) did not find out until 2000 that Jahn and Kretzschmar had at their disposal a pilot machine with a press nip in which they could vary the form of the pressure profile [Schiel et al., 2000].

Because very little data were available, a project started in February 1969 to investigate empirically how much water could be removed by extending the length of the press nip. The project was called 'Extended period pressing'. What was needed was a lab scale press, which could provide longer nip times. It was clear longer nip times could not be achieved with a conventional roll press [MacGregor, 1989]. Several suggestions were made (see Figure 3).
The so-called 'tensioned belt wrapped roll' was built (see Figure 4). The 2 metres high device consisted of a tensioned belt along three rolls with a variable angle to achieve different nip lengths [Busker, 1971]. Empirical data collected in early 1970 proved that significant dryness increases could be achieved [Busker, 2000].

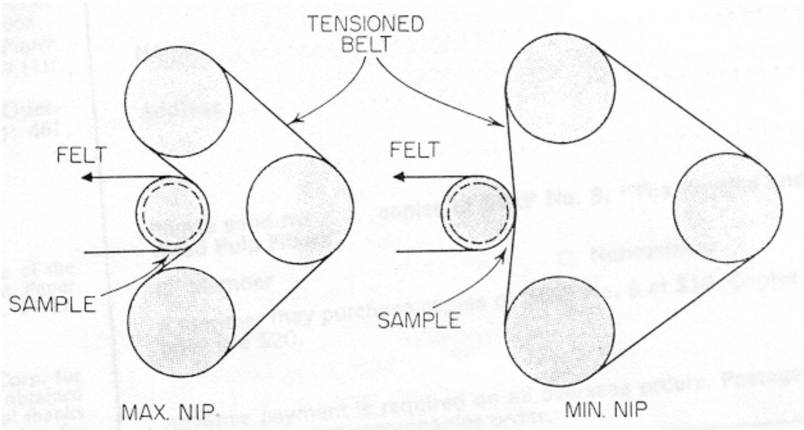


*Figure 4: The first lab scale equipment that was built at Beloit's Rockton lab (used in 1969-1970) [Busker, 2000].*

At that moment Beloit had to take the first major decision, because the lab scale press was too large to be hidden from visitors to Beloit's Rockton lab. Should Beloit publish the idea or should they wait until they had developed a technology that could be built [Busker, 2000]? There was a considerable debate whether it was better to present the idea and claim the credits or to wait until hardware was developed. One decided to present the idea of extended nip pressing to the capital-intensive paper industry in order to develop industry interest. A paper was presented at the TAPPI Engineering Conference in October 1970 and later published in TAPPI Journal (see [Busker, 1971]). To protect Beloit's position patent protection was secured [Lange, 2000; Busker, 2000]. Different designs of shoe presses were identified and a large number of patents were issued[7]. At that time it was not at all clear precisely what type of press could be engineered.

Through the early 1970s, Beloit studied the feasibility of lab scale press (see Figure 4). It was easy to obtain moderate press pressures, but after numerous tests and failures of the belts, it was apparent that press was not viable due to the weakness of the belt material [Busker, 2000]. The decision was made to build a new laboratory

[7] See e.g. [Mohr and Francik, 1974; Busker et al., 1974; Hoff, 1974; Justus, 1974].

press. The new design had two opposing hydrostatic loaded stationary shoes. The paper sheet was sandwiched between the two shoes, two belts and two felts. The belts were needed to separate the lubrication system from the paper sheet. It was recognised that the stationary shoes were difficult to apply in a continuous paper machine, but the lab device was simple to build and it allowed R&D to proceed [Daane, 1973]. A fluid medium was needed for lubrication. Water was preferred to oil. Spilling water on the paper sheet would not harm the product, whereas spillage of oil would. The sandwich-like press was operated during 1972 and 1973 with quite good results [Busker, 2000].
The decision was made to build a prototype shoe press, first to be used for experimentation and later to be installed in a commercial machine [Daane, 1973]. At some time during 1973, engineers from the US paper-making firm Weyerhaeuser came in contact with the research undertaken at Beloit. Weyerhaeuser had a strong interest in new technology during the 1970s [Woo, 2000; Vance, 2000]. The energy crises had made them more sensitive in taking energy conservation into account. Though, energy efficiency was only one of the considerations [Busker, 2000; Vance, 2000]. Engineers from Weyerhaeuser reviewed the 'extended period pressing' project. An agreement was made with Weyerhaeuser to install the prototype shoe press in one of the machines at the White Pigeon Mill (Michigan). When samples from the mill were tested, it was clear that Beloit was not yet ready to apply the technology on a commercial scale [Daane, 1973; Busker, 2000].

The difficulties encountered in identifying a design for the extended nip caused the project to lose momentum during 1973 and in early 1974 [Ritter, 2000; Busker, 2000]. There was also a growing divergence among Beloit's R&D management concerning the direction and organisation of Beloit's R&D. One did not agree about the degree to which the Research group should operate as a purely research-oriented unit[8]. Daane, who was involved in the ENP project, left Beloit. Jan Bergström became head of the Rockton lab in 1974. Justus was Bergström's boss. Bergström was enthusiastic about the potential of the extended nip and encouraged Busker to continue R&D.
In October 1974, a project was started to determine the relation between pressure and time. A small roll press was used at very low speeds. Many different furnishes were studied. The collection of data during 1975 again showed the value of the longer nip residence times. A press nip having a nip length of 50 cm would give a step increase in the dryness: sheet dryness would be 7 to 10 points higher than with conventional roll presses [Busker, 2000]. Data on product characteristics were also collected. With improved water removal came improved strength properties [Bergström, 2000].
Encouraged by these results, Bergström established a team of engineers, who critically reviewed seven different potential designs [Busker, 1976]. Bergström deliberately included people from the Development group and the engineering department. Until then the project had been of a strictly research nature [Bergström,

[8] In those days the Rockton lab was divided into a Research group and a Development group.

2000]. The team had to select the best design for the commercial application of an ENP in linerboard [Busker, 1976].

One of the seven designs studied was the ‘Figure 8 press’; the press consisted of two 25 cm shoe presses (see Figure 5). This design was patented when Beloit announced the idea of extended nip pressing way back in 1971[9] [Busker, 1976]. An important change to the original design was Bergström’s suggestion that the bearing of the shoe should be lubricated with oil instead of water. The team preferred the Figure 8 press to other designs for two reasons. First of all, two shoe press nips promised larger water removal than one nip. Secondly, the double shoe press allowed symmetry in the forces applied to the beams supporting the press [Bergström, 2000]. Gradually, the team reached a consensus that a press in a Figure 8 design could be engineered and built. Plans were made to build a pilot press[10] [Busker, 1976]. The activities of the team generated new momentum in the ENP project [Busker, 2000].

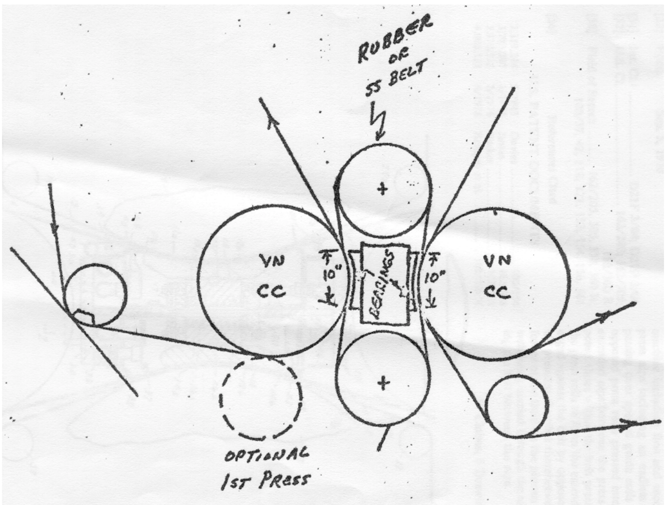


*Figure 5: Sketch of the ‘Figure 8 Press’. The paper sheet is guided through a double shoe press. Two times 25 cm press nips are located on the left and right of the load system. The belt separates the paper sheet from the oil lubrication [Busker, 2000].*

Justus suggested that the hydrodynamic bearing and oil lubrication system of the shoe press should also be tested in an existing stand-alone pilot press. Such a ‘single’ shoe press allowed an easier first test of the technical systems. This single shoe press unit became known as the X-l unit [Bergström, 2000; Busker, 2000].

In September 1977, formal approval was obtained for the plan to supply the existing pilot paper machine with a Figure 8 press. Justus and Bergström made a 10 minute presentation in front of Mr. Neese, the president and main owner of Beloit. He wanted to have the press ready in 6 months. Bergström estimated that the time

[9] See [Busker et al., 1974], US patent 3,808,096. See also [Mohr et al., 1980] and [Cronin, 1983], respectively US patent 4,201,624 and 4,398, 997.

[10] Based on US patents 4,201,624 and 4,398, 997, [Mohr et al., 1980] and [Cronin, 1983] respectively.

needed was 12 months. They agreed upon 9 months. The Figure 8 press became known as the X-8 unit [Bergström, 2000; Busker, 2000].

The construction of the X-1 unit and the X-8 unit proceeded in parallel. Dennis Cronin from the Development group was in charge of the development effort in both units. Cronin had been involved in the commercialisation of the vented nip press and the controlled crown roll[11]. His experience and his background in engineering made him very suitable to take responsibility for the development of the two pilot units [Busker, 2000; Bergström, 2000]. The X-1 unit started up in January 1978. The 25 cm shoe press proved successful almost immediately. Imagined fears regarding oil containment quickly disappeared [Busker, 2000]. The X-1 unit was supplied with felts and further studies were conducted into dewatering and product characteristics such as the strength of different furnishes [Bergström, 2000].

Exactly nine months after the rebuilding of the pilot paper machine had been approved, Bergström asked to see Mr. Neese in June 1978. The X-8 unit was running on the pilot paper machine [Bergström, 2000]. Sheet trials were carried out during the autumn of 1978. It became clear that the two 25 cm shoe presses did not perform much more efficiently than the single 25 cm shoe of the X-1 unit. It was obviously simpler to construct a single 25 cm shoe press [Bergström, 2000]. The single 25 cm shoe could achieve an increased dryness of 5 to 7% compared to a conventional roll press [Busker, 2000].

## Innovation at Weyerhaeuser's Springfield mill

The time had come for Beloit to find a customer who was willing to take the risk of investing in the first mill application of a shoe press. Beloit wanted to commercialise the first extended nip press (ENP) on an existing linerboard machine, because of the possibility to increase the machine's production capacity [Lange, 2000].

Beloit approached International Paper, the largest paper maker in the US and a big customer of Beloit. They were not interested. Then Weyerhaeuser, the second largest paper maker in the US and also a major Beloit customer, was approached [Bergström, 2000; Woo, 2000]. Weyerhaeuser had continued their interest in the ENP since their first contact with Beloit regarding extended nip pressing in 1973 [Busker, 2000]. Still, Beloit had to convince people at least at five different levels within Weyerhaeuser's organisation; the increase in production capacity and the improved strength properties were of convincing interest [Busker, 2000; Bergström, 2000; Ritter, 2000].

Weyerhaeuser became involved late in 1978. In January 1979, extensive trials were performed using Weyerhaeuser's linerboard furnish. This resulted in the placing of an order for the first commercial ENP unit in June 1979 based on the X-1 design.

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[11] Cronin was the principle developer of the vented nip press in the 1960s. Justus was the inventor of the crown controlled roll. This later roll press is technologically related to the shoe press. The roll also has an oil lubricated shoe, though it is operated from the inside of a roll press [Lange, 2000; Bergström, 2000].

Investments costs are estimated to have been around 10 to 12 million US$ (based on data in [Sirrine, 1980] and [Ritter, 2000]).
The blueprints for the commercial design of the first ENP were released in January 1980. The ENP was an open belt shoe press (ENP-O). This means that the side-ends of the shoe press were not closed; the oil lubricating the shoe and the inside of the belt was not totally separated from the paper running on the outside of the belt (see also Figure 2). It was decided to assemble the ENP at Beloit's Blackhawk plant for some preliminary trials. In October 1980, Cronin started up the first ENP. Only minor changes were needed to make the ENP run very well. Then, the unit was transported to the Springfield mill. In December of 1980, the ENP was started up. As soon as a polyurethane coated belt was installed (see next section), the results were impressive [Busker, 2000].
The agreement between Weyerhaeuser and Beloit allowed Weyerhaeuser to purchase the first five ENP presses. Weyerhaeuser exercised a large portion of this option; Weyerhaeuser bought four of the five shoe presses. The second ENP was installed in July 1982 [Ritter, 2000]. Sale of additional ENP units followed rapidly. The technology became quickly proven in board applications [Wicks, 1983].

## Last-minute belt development

Albany is a US fabric supplier to the pulp and paper industry. They supplied the belt that was needed as a 'shell' for running the paper sheet over the press and that was crucial for making the innovation a success.
In 1977 when it was decided to build the X-1 and X-8 units, belts were needed for operating these units; without a belt there was no roll shell. Beloit Manhattan, a daughter company of Beloit, was asked to supply rubber belts. Because of Beloit's earlier experiences with rubber belts, one was not very surprised that the rubber belts did not satisfy. The forces in the shoe press caused delamination of the belt. However, they could be used for testing the mechanical system and running some pilot tests.
There was still no suitable belt available when Weyerhaeuser decided to invest in the first ENP in June 1979. During the trials early in 1979, Beloit's and Weyerhaeuser's engineers were aware that the belt was a weak link, though they were confident that the belt problem would be overcome [Woo, 200; Vance, 2000; Ritter, 2000; Lange, 2000; Busker, 2000].
Early in 1980, Beloit contacted Albany. An Albany delegation visited the Rockton lab [Bergström, 2000; Ritter, 2000; Dutt, 2000]. Albany perceived the shoe press as an important innovative technology that could advance the nature of dewatering in the pressing section. They felt it was desirable to be involved [Dutt, 2000]. Dutt, one of the people in the Albany delegation, thought that a polyurethane coated fabric might be a solution. Early in the 1970s, Albany had acquired Globe Belting, a small firm that manufactured polyurethane coated belts [Ritter, 2000; Dutt, 2000]. Samples of the polyurethane coated fabric were shown to Beloit. The material looked promising. However, the size of the product made by Globe Belting did not conform

to the size needed for a commercial shoe press. Albany took on the job of developing and manufacturing a polyurethane coated belt for the ENP[12] [Dutt, 2000; Bergström, 2000].
The first properly sized belt was supplied to Weyerhaeuser free of charge as an R&D trial [Dutt, 2000]. It did not arrive in time in time for the start up of the ENP. A Beloit Manhatten rubber belt was used instead. This delaminated [Bergström, 2000; Hamby, 2000]. As soon as the Albany belt was installed, the ENP ran successfully. Without the belt, innovation would have been delayed [Vance, 2000; Busker, 2000; Dutt, 2000; Bergström, 2000].

### A role for DOE in supporting innovation?

Weyerhaeuser and Beloit were aware that the US Department of Energy (DOE) had funds for supporting development work that might lead to energy conservation. DOE was informed about the ENP during 1979. Beloit indicated how much energy could be saved if the project was successful and if a certain share of the US board machines were to install these innovative presses. DOE was interested and was prepared to cover the risk of installing the first commercial ENP. Innovation involved major capital expenditure with a high risk factor, therefore Beloit was not adverse to minimise the risk by seeking DOE's support [Busker, 2000; Bergström, 2000].
However, the waiting time for DOE support turned out to be too long. Beloit wanted to introduce the ENP as quickly as possible. Beloit did not have time to wait for DOE. Even when the first ENP at Springfield was running, Beloit had not received a concrete response from DOE. Beloit reduced the risk for both Weyerhaeuser and Beloit by covering the start-up risk with an insurance and supplying a back-up conventional roll press [Busker, 2000; Lange, 2000; Bergström, 2000]. The back-up roll press was never used [Hamby, 2000; Vance, 2000; Busker, 2000].

## 3.4. Further development of shoe press technology – after 1980

The successful innovation of the shoe press led to the emergence of a new market for machine and fabric suppliers. Table 2 gives an overview when Beloit's competitors, Voith (Germany), Escher Wyss (Germany), and Valmet (Finland) succeeded in realising their first shoe press. Figure 6 illustrates the diffusion of the shoe press.
In this section we describe how Beloit's competitors caught up and how the application of shoe press technology spread to printing paper machines too. The primary purpose of this section is to illustrate the role played by further R&D in catching up and in diffusion.

[12] The result was covered in US patent 5,238,537 [Dutt, 1993]. The original version of this patent was issued in 1981.

*Table 2: First shoe presses delivered by competing suppliers.*

| Year | Supplier | Press | Paper firm |
|---|---|---|---|
| 1980 | Beloit (US) | ENP-O | Weyerhaeuser, Springfield, US |
| 1984 | Voith (Germany) | Flexonip | Nettingsdorfer Papierfabrik, Nettingsdorf, Austria |
| 1986 | Escher Wyss (Germany) | Intensa-S | Model AG, Weinfelden, Switzerland |
| 1990 | Valmet (Finland) | Symbelt | Billerud Paper, Gruvön, Sweden |

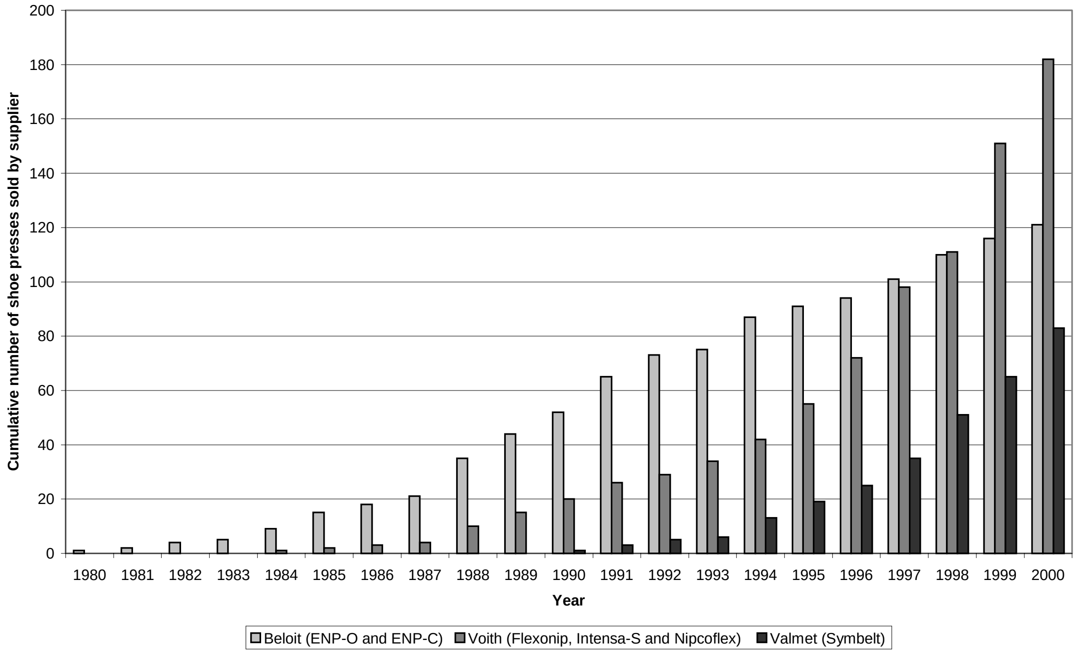


*Figure 6: Diffusion of shoe press technology. Cumulative number of shoe presses sold by Beloit, Voith (including Escher Wyss) and Valmet [Schuwerk, 2000; Kilian, 2000; Ilmarinen, 2000]. It is estimated that 10 to 15% of the annual worldwide paper production is produced on a machine equipped with a shoe press. About 25 – 35% of the shoe presses are installed on new paper or board machines.*

## The R&D activities of major machine suppliers

<u>Voith</u>

Voith had done some wet pressing R&D during the late sixties. Schiel was one of the people, who had suggested press impulse as an important concept in 1968 [Schiel et al., 2000; Schiel, 1969]. He did not continue his R&D activities in this direction, because management ordered him to develop a twin wire former[13] [Schiel et al. 2000].

Between 1974 and 1978, some wet pressing R&D was started. Nip residence time was again found to be the limiting factor. Again, a management decision stopped R&D: it was doubted whether using flexible materials as a shell (instead of steel) would ever work [Schuwerk, 2000; Schiel et al., 2000].

In 1980, rumours reached Voith that Beloit was close to realising its first ENP. When the success of the first shoe press became apparent, Voith's management wanted a shoe press of their own. Schiel led Voith's R&D activities. In 1982, the existing pilot paper machine in Heidenheim was rebuilt incorporating a shoe press.

Schiel suggested a major improvement to the design of the shoe press. He wanted to separate the oil lubrication system and the paper sheet by closing the side-end's of the shoe press. This reduced the risk of oil spillage and created higher design flexibility. Therefore, Voith needed a narrower belt, called a sleeve, than the belts supplied by Albany. Bayer (Leverkusen), a manufacturer of polyurethane, came up with a brand-new casting process for manufacturing the sleeves. Voith and Oberdorfer, a German fabric supplier and 'neighbour' of Voith in Heidenheim, formed a joint-venture for producing the sleeves.

The first Flexonip was installed in 1984 in Austria, the second in 1985 in the US [Schiel et al, 2000]. Beloit accused Voith on infringing 4 of Beloit's patents. Just prior to court action one accusation concerning the pressure profile was dropped. The judge found that Voith had not infringed Beloit's patents[14] [Schiel et al., 2000; Lange, 2000; Schuwerk, 2000].

Voith continued its R&D activities in both machine development and fabric development. This latter thing is surprising for a machine supplier. Schiel's suggestion to develop an improved sleeve coincided with Voith's decision to widen its focus and supply fabrics too [Schiel et al., 2000]. Schiel wanted to extend the lifetime of the sleeves and to improve dewatering by venting the sleeve. The grooved press rolls which were developed during the sixties had already shown the advantages of venting [Dutt, 2000; Wedel, 1993; Miller, 1999]. The first 'blind-drilled' Qualiflex sleeve was used in 1991 [Schiel et al., 2000].

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[13] Experts at Voith claim that Mr. Schiel presented the initial idea for developing shoe presses at the 2nd International Symposium on Water Removal in Mont Gabriel (1968, Canada). Schiel suggested the use the product of pressure and time for optimising water removal in existing wet pressing sections. He also noted that the form of the pressure profile of a conventional roll press was not optimal [Schuwerk, 2000; Schiel et al., 2000]. There are people who indicate Jahn and Kretzschmar's patent (Pama, East-Germany) as the first patent publication on shoe pressing [Schuwerk, 2000].

[14] This court case illustrates that: 1) earlier patents (see [Jahn and Kretzschamer, 1971]) had already weakened Beloit's patent protection; 2) small differences *in the precise formulation* can make or break the validity of a patent; 3) a patent leaves often room for manoeuvre regarding the concrete design and the technological concept. A patent litigation in case of such process technologies is a matter of arguing and convincing and not simply a matter of presenting technical details [Busker, 2000; Lange, 2000; Schiel et al., 2000].

Escher Wyss

Compared to the other machine suppliers, Escher Wyss was a relatively small machine supplier. Its R&D activities gradually expanded during the seventies. In 1979, wet pressing R&D was the newest part of the paper production process covered. The activities were not specifically directed towards shoe presses. The aim was to increase dryness and to improve paper properties.
The introduction of the ENP induced Escher Wyss to reinforce its wet pressing R&D in the direction of shoe press technology. In 1982, it was decided to install a shoe press unit in the pilot paper machine in Ravensburg. Escher Wyss started with an open belt design. They realised the disadvantages of an open belt, but sleeves were not available. Activities were continued because Escher Wyss wanted to test the mechanical design, the loading system and the lubrication system. Rupturing of the belt and the risk of oil spillage caused a loss of momentum late in 1983. The Japanese fabric supplier Yamauchi contacted Escher Wyss a year later. Yamauchi delivered a suitable sleeve and activities were restarted. The first Intensa-S press was installed in 1986 [Mirsberger, 2000].

In 1994, Voith and Escher Wyss merged[15]. The best features of the Intensa-S press and the Flexonip press were integrated. The first NipcoFlex was installed in 1996 [Schuwerk, 2000].

Tampella, KMW and Valmet

Tampella, a Finnish board machine supplier, started shoe press R&D during the late seventies[16]. KMW, a Swedish board machine manufacturer, started R&D in 1985. Both firms were bought by a third Scandinavian machine supplier, Valmet.
The Finnish Valmet started its first shoe press tests in 1983, whereas they had been doing some R&D in this direction before. At that time Valmet did not sell board machines, but the shoe press was seen as an important new development. The aim was to make shoe press technology an operational technology for printing paper machines. However, the open shoe press was unsuitable for printing paper machine, due to the higher machine speeds. Activities slowed down [Ilmarinen, 2000].
By buying Tampella and KMW, Valmet acquired a position in the board machine market. Tampella's and KMW's R&D experience in this area also became available to Valmet. As a result, shoe press R&D activities gained a new impulse in 1987. R&D was moved to Valmet-Karlstad (formerly KMW) in Sweden. Valmet also preferred a closed belt. In 1990, the first Symbelt was installed. By then, suitable sleeves were available on the market. After 1990, the character of the research

[15] Escher Wyss had already merged with Sulzer. The new firm was called Sulzer Escher Wyss. When Sulzer Escher Wyss and Voith merged in 1994, the new firm was called Voith Sulzer Paper Technology. By now, the firm is called Voith Paper Technology. In this chapter we refer to the firm as Voith.
[16] Patents indicate some activity (see [Seppo et al., 1979]).

changed. Expansion of the shoe press to other paper grades and paper quality aspects became important topics [Ilmarinen, 2000].

Beloit

Strengthened by the experience of applying ENP's at commercial board machines, R&D at Beloit centred on the use of alternative furnishes and the application of the ENP to other grades such as printing papers [Busker, 2000; Lange 2000; Wicks, 1983]. One of the important improvements that Beloit aimed at was the development of vented belts. Beloit's vented nip press, which was introduced in the early 60s, had improved dewatering capacity according to the same principle[17] [Håkanson, 1974; Busker; 2000; Bergström, 2000; Dutt, 2000]. During the late seventies, Beloit had already tried to make grooves in the belts used in the X-1 and X-8 units. However, this was going too far too quickly; a satisfactory smooth belt was not yet available [Busker, 2000; Bergström, 2000]. After the introduction of the shoe press, the idea of venting was taken up again. Successful experiments were performed in 1982. Various fabric suppliers were invited to develop the manufacturing process for the grooved belt [Lange, 2000]. The Japanese Yamauchi succeeded in the middle of the eighties [Bergström, 2000].
Whereas Beloit's ENP was a success, Beloit lost out to its competitors, who all developed a closed shoe press design as a response to Beloit's ENP-O. Beloit started the development of a closed ENP (ENP-C) in 1985, but the activities were shelved between 1988 and 1990. The ENP-O market share was excellent and it was believed that the introduction of the ENP-C would hurt sales. Furthermore, it was feared that a closed belt would reduce the lifetime of belts [Busker, 2000; Lange, 2000; Bergström, 2000]. When machine speeds increased, the risk of oil spillage became a major issue. There was nothing left for Beloit than to have a closed shoe press too [Grant, 1993; Busker, 2000; Bergström, 2000]. Further development had to be undertaken before the ENP-C could be launched on the market [Lange, 2000]. The first ENP-C was installed in the mid 1990s [Ritter, 2000].
R&D activities at Beloit on shoe press technology were stopped when Beloit's parent company filed for bankruptcy in the summer of 1999[18].

### Diffusion to printing grades

Machine suppliers continued R&D expenditure in order to extend the application of shoe press technology to printing paper grades. The first shoe press in a printing paper machine became available in 1994. It was installed by Voith [Moser, 1995]. It is only very recently that the first shoe press began to be used for sanitary paper production, also introduced by Voith (see Figure 7).

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[17] Cronin had been involved in the development of the Vented nip press [Justus and Cronin, 1964; Bergström, 2000; Lange, 2000].

[18] Beloit's mother company Harnischfegger Industries filed for bankruptcy. The downfall of Beloit had nothing to do with the market share in shoe press technology [Busker, 2000].

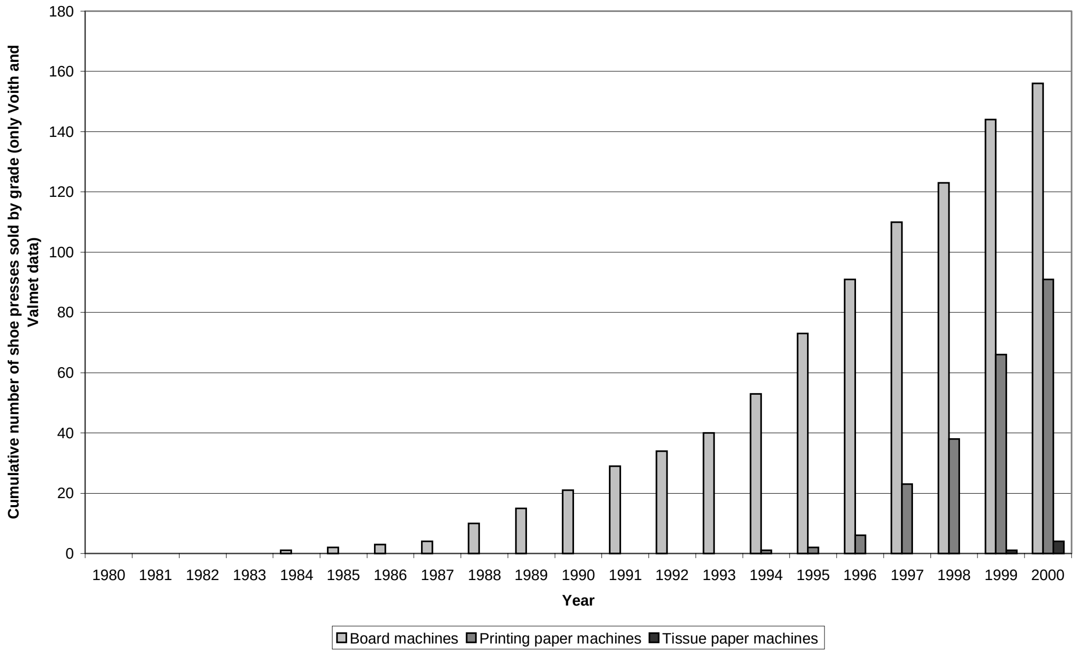


*Figure 7: The cumulative number of shoe presses started-up (only Voith and Valmet); a distinction is made between board machines, printing paper machines and tissue machines [Schuwerk, 2000; Kilian, 2000].*

Pressing of printing paper is not comparable to wet pressing of board grades. Pressing sections of printing paper machines are for instance typically single felted to prevent rewetting, but they also run at considerably higher machine speeds [Wahlstrom, 1991; Mirsberger, 1992a; Pikulik, 1999; Lange, 1997]. Some improvements were found to be advantageous for applying shoe presses to printing paper machines. First of all, the closed shoe press design was better suited to the higher machine speeds. Secondly, the grooved belts improved dewatering so that application in a single felted mode became viable. The lifetime of the belts was extended which was also important in connection with the higher machine speeds [Schuwerk, 1997; Dutt, 2000]. Thirdly, ceramic roll covers developed by machine suppliers were valuable for making single felted operation possible [Lange, 1997; Grant, 1993; Pikulik, 1999][19]. Fourthly, felt performance and lifetime improved as a result of the introduction of laminated structures [Ow Yang, 1996; Wahlstrom, 1991; Ilmarinen, 2000]. A last but very important development was the altered configuration of the shoe press in the pressing section. The main reason for changing the configuration was to improve runnability and increase paper machine speeds. Changes and optimisation of the configuration were beneficial for both board

[19] These ceramic roll cover materials were not developed specifically for use in shoe presses. Machine suppliers are interested in such covers for other reasons as well (see e.g. [Wahlstrom, 1991]).

machines and the higher-speed printing paper machines[20] [Schiel et al., 2000; Breiten, 1998; Mirsberger, 1992b].
All these improvements made it technically possible to apply shoe press technology to printing paper machines. However, accomplishing this was not a matter of R&D only. When the shoe press was introduced for the first time in 1980, the advantages of installing a shoe press were less apparent for printing grades; it was feared that important product characteristics might be lost [Mirsberger, 1992a; Lange,1996]. It took time to overcome the inertia of printing grade manufacturers and to convince them of the advantages [Lange, 2000; Dutt, 2000; Schiel et al., 2000; Mirsberger, 2000; Bergström, 2000; Ilmarinen, 2000; Busker, 2000]. But even more important was the fact that it took time before the press impulse of conventional roll press configuration became the major impediment to achieving dryness at printing paper machines. Only during the early nineties did the ongoing increase in machine speeds lead to a reduced press impulse. The need for the shoe press in printing paper grades developed [Ilmarinen, 2000; Mirsberger, 2000; Schuwerk, 1997; Meadows, 1998; James, 1999]. The rise of the shoe press in printing grades has been impressive (see Figure 7) [Lange, 1996; Moser, 1995].

## 3.5. Analysing the development

In mapping the historical development of shoe press technology we presented elements, which come back in this section in which we analyse the development of shoe press technology. First we tackle the questions formulated on the subject of the technology network, then we focus on the various micro-networks and subsequently we discuss the materialisation of the R&D activities.

### Technology network

<u>What is the composition of the technology network?</u>

There was one micro-network that undertook R&D activities to develop shoe press technology and that brought the innovative technology to the market (see Figure 8). Beloit's micro-network (US) developed the shoe press between 1967 and 1980. During the late sixties, it became widely recognised that the time-factor in the press nip limited the dewatering capacity of conventional roll presses (see Pama and Voith in Figure 8). However, only Beloit dared to engage in a prolonged effort that resulted in innovation in 1980.
Other micro-networks emerged only after the innovative technology had been introduced. Three well-known major machine suppliers (in Germany and Finland) started or reinforced their R&D activities in the direction of shoe press technology

[20] The latest vogue is a shoe press in a tandem configuration. Valmet was the first to apply this tandem configuration to a printing paper machine in 1998 [Shaw, 1998; James, 1999; Lockie, 1998].

(see Figure 8). Smaller machine suppliers did not develop their own shoe press. By the year 2000, only two micro-networks are left: Voith and Escher Wyss merged; Beloit's mother company was filed for bankruptcy. Only Valmet (Finland) and Voith (Germany) sell shoe press technology.
From the mid-eighties onwards, fabric suppliers also started R&D activities [Lange, 2000; Dutt, 2000].

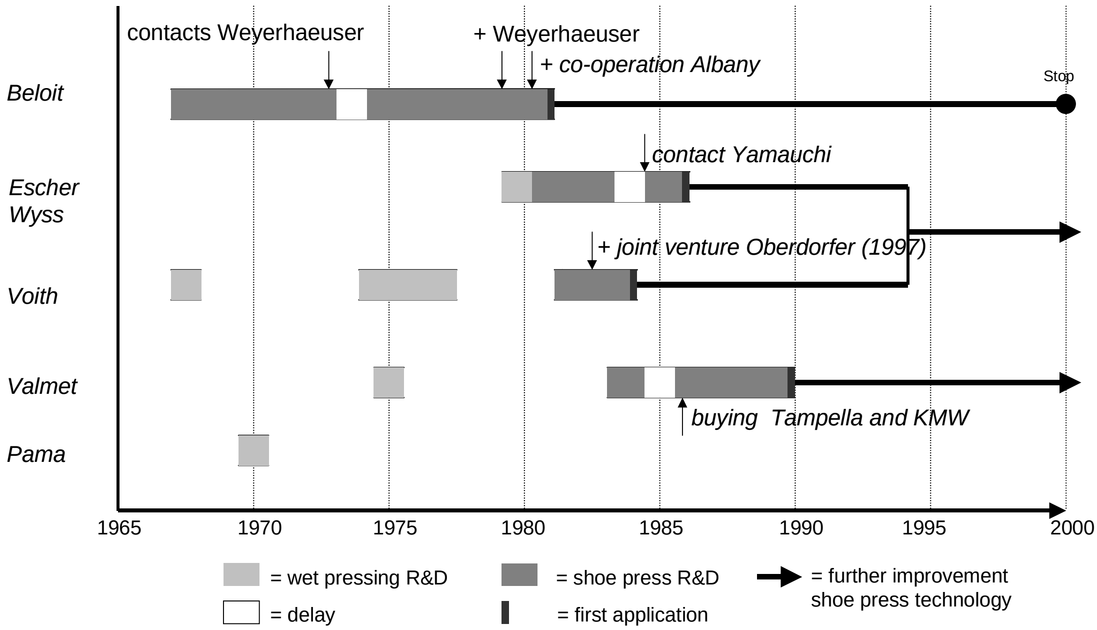


*Figure 8: Technology network of shoe press technology. Actors in normal letters are paper or board manufacturers. Actors in italics are machine or fabric suppliers.*

<u>To what extent and how often do micro-networks exchange knowledge/information?</u>

During the seventies, Beloit had no contacts with other machine suppliers. Beloit's presentation of some preliminary empirical results in 1970 at an international conference did not induce any of Beloit's competitors to develop a competing design. Apart from in-house presentations to customers and patent applications, nothing was published until the first ENP was running [Lange, 2000; Busker, 2000].
After innovation, there has been little or no contact either. Whereas some information was obtained for instance by visits to paper manufacturers with shoe presses, the competitive relationship between the firms inhibited any exchange between the micro-networks. Competing micro-networks did try to obtain information about the most recent achievements. Patents are the most important source [Schiel et al., 2000; Ilmarinen, 2000; Mirsberger, 2000]. Licences of patents is

probably the most important channel for the 'exchange' of knowledge among competing machine suppliers [Lange, 2000].

Are there dominant micro-networks in the technology network?

In this case study, there was merely one actor, who had a continuing decisive influence on the development of shoe press technology. Beloit lost its dominant position after competing machine suppliers managed to develop a closed shoe press. Voith took the lead in suggesting such a closed shoe press.

### Micro-networks

How are the various micro-networks made up?

Figure 8 shows what types of actors were involved in the four micro-networks. Machine suppliers were the driving actors in each of the four 'micro-networks'. Paper and board manufacturers became involved only when the technology was ready to be applied on a commercial scale[21]. Research institutes or universities were not involved. Belt and sleeve suppliers were important for the success of three micro-networks; Albany's belt was crucial; Yamauchi helped Escher Wyss back on track; and Voith closely co-operated with Oberdorfer.

We will now comment briefly on the contribution of the actors in Beloit's micro-network.

For almost 10 years, the development of the shoe press at Beloit was an entirely in-house affair. Although, many people contributed to the project, there were four key persons: Justus, Busker, Bergström and Cronin. Busker initiated the research that identified the process and its potential. His dedication and belief in the project were needed when the value of the project was questioned, which happened several times. Bergström brought new momentum on the project and suggested that oil should be used instead of water for the lubrication system. As R&D manager, Justus was in a position to terminate the project at any time, but he did not do so. He also conceived the single shoe press unit that was eventually commercialised (X-1 unit). Cronin's engineering expertise was important in the final phase of the project [Busker, 2000; Bergström, 2000; Lange, 2000]. The dedication of these four persons guaranteed continuity in Beloit's ENP project.

Only late in 1978 and early in 1980, did Weyerhaeuser and Albany become involved. Beloit had a good business relationship with both Albany and Weyerhaeuser. Both firms brought good technologists to the micro-network. There were open working

[21] The pulp and paper industry's R&D intensity is low. However, indirect R&D, i.e. R&D embodied in intermediate supplies and materials, is the highest among all manufacturing industries [Philips, 2000; Hatzichronoglou, 1997]. Dutch innovation statistics show that 85% of the total innovation expenditure of the pulp and paper industry goes on the purchase of equipment; only 8% is spent on R&D activities [CBS, 1998].

relationships [Busker, 2000; Lange, 2000]. Weyerhaeuser's contribution to the trouble-free introduction of the ENP-O was primarily their willingness to take the risk of being the first [Woo, 2000; Vance, 200; Busker, 2000]. Albany's contribution was to solve the belt 'problem' even at the very last moment. Fortunately, Albany had a daughter firm delivering a product that could be used as a belt. Without Albany, the introduction of the shoe press would certainly have been delayed [Dutt, 2000].

<u>What motivates actors to start and / or stop R&D activities?</u>

For Beloit, increased dryness was the main driving force. Busker wanted to achieve a 'step increase' in dryness by extending nip residence time [Lange, 2000; Busker, 2000]. By including the role of time in wet pressing, the historic trend of continually increasing pressure was broken. Whereas energy considerations were present (and one was aware of the energy crises), they were not a factor in determining Beloit's R&D expenditure for developing the shoe press [Dutt, 2000; Bergström, 2000; Busker, 2000; Lange, 2000].

Albany perceived the shoe press as an important new technology which could change the pressing section substantially. They simply wanted to be involved [Dutt, 2000].

Weyerhaeuser was interested in Beloit's ENP in 1973. Weyerhaeuser was eager for new technology. At that time, one of the factors taken into account was energy conservation [Vance, 2000; Lange, 2000]. The shoe press was not ready for commercial application. Late in 1978, Weyerhaeuser became involved again. The force that drove Weyerhaeuser to invest in the first ENP was increased dryness and thus increased production of drying-limited board machines. Strength properties were also important [Busker, 2000; Vance, 2000; Woo, 2000; Hamby, 2000]. Energy conservation and reduced energy costs only played a very minor role [Lange, 1997; Lockie, 1998].

Why did none of the other major machine suppliers undertake R&D activities to develop a shoe press? All three competitors had plausible arguments for 'waiting'. Valmet had no real business interest in the board machine market at the time [Ilmarinen, 2000]. Escher Wyss was a relatively small supplier and did not cover all machine areas in their R&D portfolio [Mirsberger, 2000]. At Voith, management halted wet pressing R&D twice. In 1968, other innovative technologies had the priority. In 1978, it was not believed that a flexible shell would be an alternative for the conventional steel roll press and that it would be accepted by the manufacturers [Schiel et al., 2000].

Though, the most important argument why Beloit's competitors waited might have been that Beloit had taken a major step from an engineering point of view. It was widely known that time limited dewatering in the press nip, but nobody could think of a design to overcome this limitation. Or as Ilmarinen (Valmet) put it: *"Maybe nobody believed that it was possible to find real operating solutions" [Ilmarinen,* *2000]*. At Beloit, they continued to believe in using belts as a shell for extending nip residence time [Schiel et al., 2000].

Shortly upon its introduction, shoe press technology became a 'proven technology' for board grades. The success of the technology forced machine suppliers and fabric suppliers to catch-up. Suppliers invested in R&D to improve the performance of shoe press technology for board grades and to extend the application of shoe presses to printing grades.

How much money is spent and by whom?

Table 3 gives an overview of R&D expenditure by the major machine suppliers.

*Table 3: R&D expenditure.*

| **Machine supplier** | **Time frame** | **Total expenditure (million US$)** | |
|---|---|---|---|
| Beloit[1] | 1967 – 1980 | 5<br>0.35 - 0.4 | total expenditure (excluding innovation)<br>annual budget |
| | 1980 – 1999 | 8<br>0.4 | total expenditure<br>annual budget |
| Voith[2] | 1980 – 1984 | 0.7 | total expenditure |
| | 1984 – now | | 8 shoe presses on pilot paper machines. No estimates about labour costs. |
| Escher Wyss[3] | 1979 – 1986 | 0.7<br>0.1 - 0.15 | total expenditure<br>annual budget |
| | 1986 – 1994 | | continued at the same level (annual budget) |
| Valmet[4] | 1983 – 1990 | | No estimates available. Normal development work; no special efforts needed. |
| | 1990 – now | | R&D expenditure continued at the same level (annual budget). |

[1] US dollars were converted to 1995 US dollars. Busker (2000) supplied 'really rough estimate of ENP research & development costs'. Between 1968-1977, annual costs were estimated to have been 80,000 US$ (two man-years). Between 1977-1980, costs were roughly 1.5 million US$ (construction of pilot presses). Costs of patents are not included. Beloit spent about 6.5 million US$ between 1980 and 1999 [Busker, 2000; Lange, 2000]. [2] The estimation (1980-1984) is based on the rebuild of the pilot paper machine and two times 3 fte's. German marks were converted to 1995 US dollars (using PPP) [Schiel et al., 2000; Schuwerk, 2000]. [3] [Mirsberger, 2000]. [4] [Ilmarinen, 2000].

The four machine suppliers spent in total less than 10 million US$ in bringing their first shoe presses to market. This is a modest sum compared to the annual R&D budget of each of the machine suppliers, i.e. between 40 to 75 million US$ *annually* (typically 3-4% of the turnover) [Luiten, 1997]. It is not very surprisingly that the absolute R&D investments in shoe press technology after 1980 increased considerably compared to the annual expenditure between 1967-1980; there were more actors investing in shoe press R&D and one had to invest in pilot paper machine equipment. Machine suppliers continued to spend roughly the same amount annually on shoe press R&D (see Table 3).

R&D development of shoe press technology did not receive any financial support from government. There was some contact between Beloit and the US Department of Energy (DOE) with regard to covering part of the risk of innovation at Weyerhaeuser. However, the additionality of government R&D support would have been very limited, because innovation also took place without DOE's R&D support [Bergström, 2000; Lange, 2000].

<u>What important decisions are made with regard to the direction of technological development?</u>

Beloit and Albany made important design choices. They constructed the model that 'broke' with the conventional roll press design. Others could start their developments from this model [Ilmarinen, 2000].

The case study illustrates that apparently simple decisions can have a crucial impact on the final design and, also, on final (business) success. These illustrations make clear that decisions are taken in bounded rationality.
From 1975 to 1978, the people at Beloit were convinced that a double shoe press (X-8 unit) was needed to reach a substantial increase in dryness [Busker, 2000]. A stand-alone X-1 unit was build in addition to the X-8 unit merely to do some quick mechanical testing [Bergström, 2000; Busker, 1976]. However, the X-1 unit became the final design model [Bergström, 2000].
A second illustration is that Bergström insisted on using oil instead of water in 1977. For about 4 to 5 years water was preferred; one simply feared spillage of oil. The use of oil turned out to be important for the feasibility of the technology.
Beloit designed an open shoe press (ENP-O). The belt was easier to manufacture and it had been difficult enough to develop it in the first place [Mirsberger, 2000; Schiel et al., 2000]. Or as Busker said: *"We needed to walk before we could run" [Busker, 2000]*. Additional R&D would have been needed to transform the ENP-O into a closed design and Beloit wanted to get the technology introduced as quickly as possible [Bergström, 2000].
A fourth illustration is that Beloit started to develop a closed design in 1985, but the decision was made to shelve the project. Beloit failed to recognise the merits of a closed design compared to their – at that time – very successful open shoe press design. It was a matter of time (and of increasing machine speeds), before the advantage of the closed shoe press design became visible.

### Materialisation

<u>What is the rate of development and what steps in up-scaling can be distinguished?</u>

Whereas the idea of 'press impulse' (and the importance of time) was rooted in wet pressing R&D, we consider Beloit's R&D activities as the start of the development of the shoe press. It took Beloit about 13 years to introduce the shoe press to the market (see Figure 8). It took Voith 4 years to develop their closed shoe press (1984). Escher Wyss needed 6 years and Valmet 7 years. Shoe press technology was first applied to board machines. It took till 1994 before the 'first' shoe press was applied to a printing paper machine (see Figure 7).

Beloit's R&D activities can be divided roughly into two phases. The first phase (1967-1976) covered laboratory activities. Whereas the basic idea to extend the nip residence time had been clear since the very first year, the researchers at Beloit were looking for a way to build the press. Different designs were explored and patented (see also Figure 3 - Figure 5) [Busker, 2000]. In 1973, an attempt to arrive at a commercial prototype failed. After that R&D activities slowed down (see also Figure 7). In the second phase (1977-1980), the ENP project regained momentum. Commercialisation resulted within 3 years [Lange, 2000; Busker, 2000; Bergström, 2000].

After 1980, all competing machine suppliers started working on their existing pilot paper machines. Escher Wyss needed 2 years more than Voith to bring its first shoe press to the market. Escher Wyss 'waited' for a fabric supplier to deliver a belt/sleeve for the closed shoe press, whereas Voith developed a sleeve in co-operation with a fabric supplier [Schiel et al., 2000; Mirsberger, 2000]. Valmet introduced their shoe press only in 1990. Their R&D activities persisted only when Valmet gained an interest in the board machine market by buying KMW and Tampella [Ilmarinen, 2000].

A large number of patents resulted from the development of shoe press technology[22]. Beloit had tried to secure the best possible patent protection in 1971, although experts discussed (and even doubted) the value of patents in the machinery area. It is often relatively easy to circumvent patents, especially if the patents are becoming more and more detailed. It is also often hard to prove that your patent has been infringed. A prior patent can often be found (as e.g. in this case the East-German patent). Furthermore, minor differences in formulations can make or break the validity of a patent as happened also in this case: Voith's second shoe press was built in the US [Busker, 2000; Bergström, 2000; Mirsberger, 2000; Schiel et al., 2000]. The largest value of filing a patent might be that an inventor has to rethink his design very systematically when he is writing the patent application. Patents end up as 'trading material' between firms ('you can use my patents if I can use yours') [Busker, 2000; Bergström, 2000; Schiel et al., 2000].

<u>What are the perceived performance characteristics of the technology?</u>

It was clear from the moment that development started that increased dryness was the major advantage of the shoe press [Lockie, 1997; Shaw, 1998; Lange, 1997]. Improved strength properties and increased dryness (read: increased production)

[22] We estimate that there are 50 to 100 patents on shoe press technology.

explain the successful *diffusion* of the shoe press in board grades [Woo, 2000; Busker, 2000; Mirsberger, 2000; Woo, 2000].
Extensive technical improvements in shoe press technology itself, the configuration and the felts were suggested by machine suppliers to convince printing paper manufacturers of the value of shoe press technology for paper grades. Paper manufacturers were however not convinced of the value of the shoe press. It took time to overcome their inertia. Technical improvements alone were not enough. As time went on and machines speeds increased, the reduced press impulse became a major impediment to achieving a high dryness at the exit of the pressing section. Only by then, printing paper manufacturers were willing to apply shoe press technology too [Mirsberger, 2000; Schiel et al., 2000; Lange, 1997].

## 3.6. Robustness of analysis

Data gathering was based on two sources; the written material and consultation of experts. We collected all the articles and papers written about shoe press technology. Pulp & Paper magazines, (scientific) journals and conference proceedings were searched. We also searched patent databases. Patent databases contain information on a tremendous amount of patents related to shoe press technology. We estimate that there are 50 to 100 patents. Most patents only cover details. A substantial number of these patents were never used commercially.
Not all the topics we are interested in are covered in written material. We consulted experts for gaining a better understanding of the role of actors, networks and actors' arguments. This source of information introduces a dependency on the willingness and the capability ('what do they know themselves and what do they remember?') of experts. Their response may also be biased by their perception of the development history. Secrecy is less of a problem in this case study; the development is historical.
Experts from firms who played an important role within the various micro-networks were consulted (Beloit, Albany, Weyerhaeuser, Voith, Escher Wyss and Valmet). The persons spoken to had all been deeply involved in R&D directed towards shoe press technology. Interviewing these experts was an iterative process; after each interview other experts were asked new questions that enabled us to get feedback on specific topics. It enabled us to unravel differences of opinions about certain topics and to obtain information on points that had been forgotten.
We are thus convinced that the mapping of the technology's history is robust. The analysis is thorough and soundly based on written and interview material. We have detailed and complete information about the micro-networks.

## 3.7. Conclusion

Shoe press technology, one of the major innovations in the paper and board industry in the 20th century, is considered to be an 'energy-efficient technology'. Our aim was to investigate the balance between internal factors – characteristics of the actors – and external factors – network linkages between actors and actors' embeddedness in a specific industrial context – in both the R&D development (1.) and in the further improvement of shoe press technology since the moment of innovation (2.).

1. Although external factors – like a broader understanding of the importance of the factor time in wet pressing R&D; that Beloit's R&D activities were based on a thorough knowledge of the needs of their customers; and that Beloit was one of the most respected major machine suppliers –, *internal* factors were decisive for the development of shoe press technology.

With the important exceptions mentioned, we can say that on the whole external factors played only a minor role in the R&D development:

- The R&D activities were not undertaken in direct response to the wishes of customers.
- Technological development at Beloit was not driven by a sudden increase in the price of energy or raw materials, which affect the competitiveness of Beloit's customers. The higher energy prices during the seventies did not affect R&D expenditure at Beloit.
- Government did not play any role in forcing or stimulating role these activities.
- There were no sudden disruptions or changes in the pulp and paper industry that stimulated efforts to extend the nip residence time.
- Researchers and engineers at Beloit were not influenced by interaction within a technology network.

Beloit succeeded in developing a press design that broke with the model of the conventional roll press. From an engineering point of view, shoe press technology was a 'major' step to take; a flexible roll shell was used instead of steel, so that the nip residence time could be extended. Other researchers were aware that 'press impulse' was important for optimising wet pressing performance, however, only Beloit undertook continued R&D activities. In spite of some delay caused by the trouble in finding a press design that worked, the technology that resulted was both successful and innovative. Certain characteristics of Beloit (or of the people pushing the development of the shoe press at Beloit) were important for the successful development of the shoe press:

- Beloit allowed its workers to start R&D in a direction that was thought to be good for the customer, even though there were no plans for a concrete product.
- Previous R&D and engineering experience turned out to be of crucial importance in bringing the technology towards the market.

- Researchers and management showed courage and continuing dedication to develop the technology; Beloit ‘believed’ in something that other machine suppliers did not yet see.

And finally, at certain moments the right elements simply came together, think for instance of the development of the belt. Success needed some coincidence too.

2. Whereas internal factors explained part of the success of further improvements during diffusion, external factors primarily led to the further improvement of shoe press technology. R&D activities and improvements were driven by the market success of shoe press in board grades and the emerging need for an increased press impulse in printing paper machines.

The most important external factors that have triggered improvements since 1980 are:
- The shoe press performance fitted in with the needs of board manufacturers: higher machine speeds, improved strength properties and reduced raw material costs were appreciated. Once the technology became proven, an interesting market emerged. To capture a market share, competing machine suppliers, felt suppliers, and belt/sleeve suppliers had to develop a position in the technology network.
- The emerging technology network led to a fruitful spill-over among actors, especially between belt/sleeves suppliers and machine suppliers.
- Board manufacturers’ requirements (better runnability and increasing machine speeds) drove important technical improvements in the configuration of shoe press within the pressing section.
- Continually increasing machine speeds of printing paper machines was an important factor in overcoming the inertia of printing paper manufacturers. This led eventually to the need for shoe presses in printing grades; the press impulse of conventional roll presses became a major impediment.

These external factors made it easier for other machine suppliers to follow Beloit. However, internal factors were important in determining the course of events in the development of the technology network:
- Voith was the only machine supplier that developed considerable R&D expertise in the sleeve area because they wanted to improve Beloit’s original design. This explains why they were able to catch up with Beloit in only 4 years and explains part of their later market success.
- Actors’ strategic decisions (concerning matters like developing a new area of knowledge e.g. belt or not; stopping R&D because the technology was unsuitable for the main market segment covered; restarting R&D due to the acquisition of other machine suppliers; or continuing to believe in the open press design that was originally developed) impacted on the further development of the technology network.

A final question is whether shoe press technology can be regarded as an innovative energy-efficient technology? Although shoe press technology – most often – improves the specific energy consumption in manufacturing paper or board, energy efficiency was not a decisive argument in the development of shoe press technology. It is neither a decisive argument for paper manufacturers to invest in the implementation of shoe press technology.


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# Chapter 4

# Impulse technology[1]


### Abstract

*Impulse technology is a paper-making technology that increases dewatering and therefore reduces the need for evaporating drying. In this chapter, we evaluate the effect of government R&D support on the development of impulse technology by looking at the networks within which the technology is developed.*

*Douglas Wahren, the inventor of impulse technology, anchored impulse R&D activities at the US national pulp and paper research institute 10 years after his first idea of impulse technology. A first micro-network emerged when the US machine supplier Beloit and the Canadian national pulp and paper research institute also initiated R&D activities. Both research institutes claimed an increased energy efficiency to obtain government R&D support. A second micro-network emerged in Sweden from 1990 onwards. A Swedish government representative offered the national pulp and paper research institute financial R&D support in order to start the development of this energy-efficient technology. After six to seven years of planning, talking and negotiating, a major R&D programme was started. Only the Swedish micro-network is still active.*

*The major argument for developing impulse technology was an increased machine capacity in existing paper and board machines and a reduced capital intensity in new paper and board machines. Wahren's original claim dewatering claims became less strong over time. Actors' arguments for investing in impulse technology, thus, also changed. Paper properties were increasingly stressed. However, more than 25 years of R&D activities – and 15 years of government R&D support – have not yet resulted in a proven technology. In fact, its prospects are unclear; its energy-efficiency improvements are uncertain; its feasibility is being debated.*

*A first conclusion is that the government R&D support undoubtedly accelerated the development of impulse technology. A second conclusion is that the strategy and decisions of national pulp and paper research institutes were decisive in the acquisition and utilisation of government R&D support. R&D activities drove government R&D support instead of the other way around.*


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[1] A preliminary version of this chapter was earlier published (see [Luiten and Blok, 1998]).

## 4.1. Introduction

Improving the energy efficiency of the energy-intensive manufacturing industry is seen as one of the most important options for reducing the emissions of gases which contribute to anthropologically-induced climate change (see e.g. [IPCC, 1996; UN, 1997]). In addition to the techno-economic potential of commercially available energy-efficient technologies (see e.g. [De Beer et al., 1994; WEC, 1995; IWG, 1997]), analysts are increasingly interested in the long-term potential of innovative energy-efficient technologies. Such technologies may lead to a continuous improvement in energy efficiency in the manufacturing industry (see e.g. [De Beer, 1998; Martin et al., 2000a; IPCC, 2001]). A considerable long-term potential is claimed but what can government do to stimulate the development of such innovative industrial energy-efficient technologies? It is often suggested that government R&D support is as an important policy instrument for accelerating the development of such technologies (see e.g. [Blok et al., 1995; De Beer, 1998; Elliot and Pye, 1998]). However, little is known about the actual effect of government R&D support on the development of industrial energy-efficient technology.

In this chapter we explore the development of a specific industrial energy-efficient technology to which government has contributed substantially by financing R&D activities. We want to increase our insight into how government R&D support plays a role in developing energy-efficient technologies. For this purpose, we go beyond an evaluation in financial terms. We want to know who were involved in developing the technology and what were their arguments were. We must discover how important government R&D support was for these actors.

In this chapter we examine the effect of government R&D support on the development of a specific energy-efficient technology. For this purpose we make a detailed investigation of the networks in which impulse technology is developed. Impulse technology is a wet pressing technology for the paper industry, which is one of the energy-intensive manufacturing industries [WEC, 1995]. Impulse technology is frequently mentioned in overview studies regarding emerging energy-efficient technologies and is, therefore, an interesting case study (see e.g. [Arthur D. Little, 1998; IWG, 1997; De Beer, 1998; Martin et al., 2000a; Martin et al., 2000b; IPCC, 2001]).

In the Section 4.2, we briefly introduce the paper production process and impulse technology. Subsequently in Section 4.3, the historical development of impulse technology is mapped. In this description we focus on the issues that are of interest for our analysis in Section 4.4. In Section 4.4, we structure our analysis of the case study by answering questions about the technology network, the two micro-networks and the materialisation of the technology (so far). In Section 4.5 we discuss the effect of government R&D support on the development of impulse technology. After a short discussion of the validity of the analysis (Section 4.6), the chapter closes with brief conclusions (Section 4.7).

## 4.2. Making paper and impulse technology

### Making paper

The basic principles of paper-making have not changed since the process became mechanised during the first half of the 19th century. Making paper in a conventional non-integrated paper mill generally consists of three clusters of activities: furnish preparation, paper machine and finishing operations.

In the furnish preparation, pulped wood and/or waste paper are screened and prepared. The fibres are mixed with water, some chemicals and other additives. This mixture is called furnish. The percentage of dry solids in the furnish, also called the dryness of the paper sheet, is about 1%. The furnish is fed to the paper machine. The machine itself can be divided into three sections in which the water is removed from the paper sheet. Dryness increases as the paper sheet moves along the paper machine (see also Figure 1). The three sections are as follows:

1. Forming section: forming the paper sheet while draining and suctioning
2. Pressing section: mechanical dewatering by passing the paper sheet through a number of press nips
3. Drying section: evaporative drying of paper sheet

Finally, finishing operations such as calendaring, winding and cutting are needed to deliver the final product.

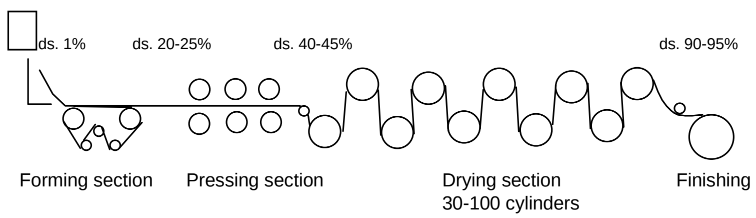


*Figure 1: Conventional paper machine. DS = percentage of dry solids in the furnish, also called the dryness of the paper sheet.*

The drying section of the paper machine requires the largest amount of energy per unit water removed because the water has to be evaporated. Improvements in the energy efficiency of a paper machine are therefore typically directed at reducing the energy requirement of drying (see e.g. [de Beer, 1998; Martin et al., 2000b]). The specific energy consumption can be reduced by improving drying technologies or by increasing water removal in the pressing section.

### Impulse technology

Impulse technology increases the sheet dryness at the exit of the wet pressing section and therefore reduces the need for evaporative drying. An impulse press nip is inserted between the conventional pressing section and the drying section (see Figure 2).

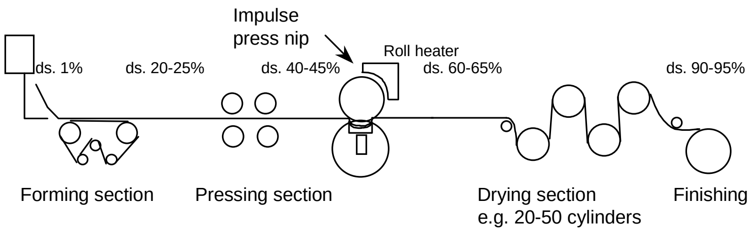


*Figure 2: Typical paper machine with one impulse press nip. DS = percentage of dry solids in the furnish, also called the dryness of the paper sheet.*

In a conventional paper machine, two different types of presses are used. The first and oldest type has two counter-rotating rolls (compare Figure 1). The second type of press is the shoe press, which was introduced in 1980. Impulse technology is one of the most recent ideas for improving wet pressing. Impulse technology requires a shoe press nip.

In an impulse press nip, the paper sheet is fed between a felted shoe press and a (coated) roll. The roll is heated (most often using induction-heating equipment) to a temperature between 200ºC and 350ºC. The heated press roll transfers heat to the paper sheet and simultaneously pressure is exerted by the shoe press (2-8 MPa). Pressure and temperature are the driving forces behind dewatering in impulse technology.

Impulse technology has several advantages. First of all, it may reduce the amount of energy needed to produce paper by reducing the amount of steam needed for evaporation. Although additional energy is needed in the pressing section (electricity is commonly used), this increased energy use is likely to be offset by the reduced demand for steam.

Secondly, an improved water removal process means that either the production capacity of an existing paper machine can be increased (most paper machines run ‘dryer limited’, meaning that the production capacity cannot be increased due to the limited drying rate of the drying section), or it means that the investment costs for a new paper machine can be decreased (capital expenditure on drying cylinders will decrease because fewer drying cylinders are needed).

Finally, impulse technology may improve paper properties. There is no doubt that the increase in temperature and pressure affect the physical properties of the paper, although the ultimate impact on paper properties has not yet been ascertained.

For a better understanding of the development history of impulse technology, one needs to be aware of two phenomena.

First of all, impulse technology is *claimed* to have a ‘special’ dewatering mechanism; it is not normal wet pressing, neither is it evaporation. The original idea is that the heat flux generates a steam gradient in the paper sheet, which displaces liquid water from the sheet into the receiving felt. The hypothesis of a vapour front displacing liquid water was suggested by the inventor of the technology to explain the increase in water removal (see [Wahren, 1982; Arenander and Wahren, 1983]). The theory of steam formation has not been confirmed yet. Steam is formed, although it is not certain whether this occurs *in* the nip. Secondly, delamination has been a major bottleneck. Delamination occurs when the paper sheet strength cannot withstand the vapour pressure in the paper sheet. When the paper sheet emerges from the press nip, the external consolidating pressure is removed and the water in the sheet flashes into steam. If the internal vapour pressure is too high the paper sheet cannot hold together and the sheet delaminates. The paper sheet is destroyed. It is claimed that different paper grades differ in their susceptibility to delamination. It is therefore useful to make a distinction between *heavier-weight* grades (typically packaging- and board-grades such as linerboard) and *light-weight* grades (typically printing paper grades such as newsprint and light-weight coated paper).

## 4.3. Historical development of impulse technology

In this section the historical development of impulse technology will be mapped. After describing Douglas Wahren's R&D efforts in Sweden (1970-1978) and early R&D activities in the US (1978-1987), we document the failed attempt to commercialise impulse technology (1987-1989). We then describe the Canadian R&D activities (1983-1994). Subsequently we comment further on the US attempts to solve the problem of delamination. We make a distinction between the early attempts (1988-1995) and the more recent attempts (1995-1999). Then the emergence of R&D in Europe is outlined. We describe the attempts to engage in pre-competitive co-operative R&D activities within the International Energy Agency's pulp and paper Implementing Agreement. Finally, we briefly mention the R&D activities of two other major machine suppliers. In mapping the history of impulse technology, we emphasis elements which are taken up again in our later analysis of the technology's development in Section 4.4.

In our description, we make a distinction between laboratory platen presses, laboratory roll presses and pilot paper machines. A laboratory platen press consists of two platens, which are simply pressed against each other with a piece of paper sheet between them. A laboratory roll press can process a continuous paper sheet between two press rolls and bears a greater resemblance to commercial paper machines than platen presses [MacGregor, 1989]. The laboratory roll press is a stand-alone unit. Typical speeds range from 50 to 300 m/minute. The width of a roll press is typically less than a metre. A pilot paper machine is often a complete paper machine but has a limited width (up to 1 metre, often smaller). It runs at commercial machine speeds, i.e. 1,000 – 2,000 m/minute.

## 1970-1978: R&D in Sweden – the idea for impulse technology

Douglas Wahren is generally acknowledged to be the inventor of impulse technology. In the early seventies he was working at the Swedish Skogsindustrins Tekniska Forskningsinstitut (STFI)[2] and the Kungliga Tekniska Högskolan (KTH) both in Stockholm. Because of the huge capital required for the drying section of paper machines, Wahren asked himself: how fast can paper be dried? He considered heat transfer to be the key to the problem: by pressing harder and simultaneously increasing temperature, it should be possible to transfer heat very rapidly to the paper sheet. Wahren performed a crude experiment with a laboratory platen press. Only milliseconds were needed to transfer the heat needed to dewater the sheet. Due to lack of time and resources for hiring a suitable person, the idea was shelved [Wahren, 1998].

In 1973, Wahren moved to KMW to become vice president of research[3]. KMW was a Swedish machine supplier to the paper industry. Wet pressing was one of KMW's R&D priority areas. In 1976, there was an opportunity to start an entirely new project in wet pressing. Wahren told Zotterman, who was hired to perform the wet pressing R&D, about his idea concerning rapid dewatering at both high pressure and high temperature. Wahren speculated that the formation of steam induced a pressure gradient that 'pressed' liquid water out of the paper sheet into the felt. Wahren and Zotterman evaluated not only impulse technology but also various other ways of 'intense pressing/drying', e.g. drying between a hot and a cold surface[4]. Since KMW was a relatively small machine supplier, KMW could not pursue both the impulse and the hot/cold sandwich projects. Wahren chose impulse technology, which had the best potential for making a compact (and thus capital extensive) paper machine [Wahren, 1998].

By 1978, a heated impulse press nip (using two rolls) was running on KMW's pilot paper machine. The pilot paper machine was run at a slow speed to achieve the nip residence time required, i.e. 600 m/min. In 1978, Wahren applied for a patent to protect KMW's interests [Wahren, 1978]. However, the idea was again shelved; the product properties – 'hard, stiff and strong' - were not suitable for KMW's main market at that time which were tissue machines. At the end of 1978, Wahren decided to leave KMW [Wahren, 1998].

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[2] The Swedish national pulp and paper research institute (STFI) is a national specialised pulp and paper research institute that is primarily financed by the national pulp and paper industry. Each member firm pays an annual membership fee and gets research results in return. Such a national pulp and paper research institute exists in almost all countries where pulp and paper manufacturing is an important manufacturing sector, e.g. IPC / IPST in the US, Paprican in Canada, and KCL in Finland. In the mid-1990s, some of these national pulp and paper research institutes allowed supplying firms to become members of the research institute. Beloit became a member of IPST in 1995. Valmet-Karlstad became a member of STFI in 1995.

[3] KMW became a part of Valmet-Karlstad in 1986. Valmet-Karlstad is part of Valmet, a Finnish machine supplier. Carl Zotterman is now vice-president of research at Valmet.

[4] The idea of drying between a hot and cold band is comparable to the Condebelt dryer, which was developed by Tampella, another Finnish machine supplier. Valmet also bought Tampella.

## 1979-1987: R&D in the US – IPC and Beloit

Wahren moved to the Institute of Paper Chemistry (IPC) in Appleton in February 1979. IPC was the US national pulp and paper research institute, similar to STFI for the Swedish paper industry. In 1979, IPC took on new staff in order to re-organise the institute. Wahren was hired as head of the research and had to rebuild R&D which had deteriorated considerably.

Posner, IPC's vice-president, was aware of Wahren's idea about wet pressing under intense heat and pressure. He was excited and suggested the term 'impulse drying'[5]. Wahren's plans to develop expertise in (modelling of) heat and energy transfer processes were supported by IPC's board. Within a year he succeeded in getting people on board with expertise in this area. Zotterman was one of the persons hired. This preliminary research was financed by IPC's membership dues [Wahren, 1998].

Some first results were presented in 1981 at IPC's annual member conference [Ahrens, 1981]. In 1983, a first article was published: extremely high drying rates up to 30,000 kg $H_2O$/hr $m^2$ were reported and it was claimed that one press nip could achieve a dryness increase of 20%[6]. In the article, Arenander and Wahren attributed the high dewatering rates to the special dewatering mechanism: *"Transport of interstitial water out of the sheet (occurs) by means of the steam generated pressure gradient or steam flow through the sheet" [Arenander and Wahren, 1983, p.124]*.

Wahren contacted Beloit, a US paper machine supplier. Wahren's first industrial job was at Beloit. He knew Jan Bergström, who was the manager of the Beloit's Rockton lab, quite well and appreciated Beloit's competence. In March 1981, representatives of Beloit (amongst others Bergström) visited IPC. Wahren offered Beloit 'full co-operation' [Wahren, 1998; Wahren, 2000; Bergström, 2000; Orloff, 2000; Busker, 2000].

Beloit started its own research activities in 1981. The suggested mechanism behind impulse technology was new and intriguing. Beloit's main interest was the potential reduction in size of the capital-intensive drying section in new paper machines and the increased production capacity of existing dryer limited machines [Bergström, 2000; Busker, 2000]. The researchers at Beloit suggested that a shoe press had to be used instead of a roll press. For Beloit, impulse technology was a logical and

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[5] There have been a lot of names for what we in this article indicate as 'impulse technology'. Each actor had his own favourite. IPST coined the name 'impulse drying'. Albany wanted to call 'impulse drying', 'impulse pressing'. Beloit referred to it as High Temperature Pressing (HTP). Later when Beloit designed the induction-heated press for the No. 2 pilot paper machine we titled it High Efficiency Drying, but no one at Beloit liked the shortened version HED. STFI coined the name 'impulse technology'. In using the term impulse technology we do not for favour any naming of any of the actors. We use the term technology in other case studies towards the development of industrial energy efficient technologies.

[6] The drying rate is the water removal minus the water removal rate in pressing at room temperature. This should be evaluated a drying rate of 15-30 kg $H_2O$ / $m^2$ hr in drying cylinders. The drying rate is compared to the drying rate of drying cylinders, because Wahren and Arenander suggest impulse technology as a replacement of drying cylinders (dryness at the entry of the impulse press nip in the range of 40 to 60% dryness) [Arenander and Wahren, 1983].

interesting step after Beloit's successful development and introduction of the shoe press[7]. There was continued contact between Beloit and IPC staff, though no formal co-operation [Crouse, 1998; Bergström, 2000; Wahren, 2000]. Beloit used a laboratory roll press [Crouse et al., 1989]. Fairly soon Beloit realised that a new type of felt was needed to resist the extreme wet pressing conditions. Beloit contacted different felt suppliers, one being Albany [Bergström, 2000; Crouse, 2000].

After the preliminary laboratory experiments, IPC wanted to continue its R&D activities on impulse technology. Therefore, Wahren and Sprague contacted Sobczynski in 1984. Sobczynski was the programme manager for the pulp and paper industry at the US Department of Energy (DOE). DOE was asked for financial support. Sobczynski considered impulse technology as a promising technology: it was a high risk R&D project but promised to improve energy efficiency and the competitiveness of US paper and board industry. There was no specific programme for the pulp and paper industry, but Sobczynski managed to supply IPC with a subsidy to evaluate three innovative pressing/drying technologies in 1985. IPC used a laboratory platen press[8]. The final report to DOE claimed that impulse technology was the most radical and the most energy efficient of the three technologies considered (see [Sprague, 1985]).

Sprague prepared an unsolicited proposal for continuing impulse R&D at IPC. Following the review by pulp and paper industry's experts, DOE continued to support IPC [Orloff, 1997; Sobczynski, 1998]. IPC's member dues were used as an additional source of finance [Fleischman, 2000]. A new lab platen press was built in 1986. The aim was to use the platen press for creating a database on product properties and energy requirements for different paper grades. Promising results were reported in the annual report which was delivered to DOE at the end of the first year support (see [Lavery, 1987a]).

Additional DOE support was acquired. A 1.5 million US$ subsidy for a period of 4 years was granted for the construction of a laboratory roll press with two press nips. The second press nip was needed to minimise differences between the two sides of the paper sheet of light-weight grades [Lavery, 1988]. The construction of the first press nip started late in 1986. A second press nip was added late in 1987 [Lavery, 1987b; Orloff, 1989].

The laboratory roll press was never used intensively. The 2nd, 3rd and 4th annual reports, which were written annually to supply DOE with an overview of how government financial support was spent, announced extensive plans for using the lab roll press to evaluate the product properties of a variety of commercially important paper grades. However, these plans were never executed. Only the 3rd annual report presented some empirical results using the laboratory roll press. In the 4th annual

[7] Beloit had developed the shoe press between 1967 and 1980 (see Chapter 3).

[8] The evaluation considered: drying at elevated temperature and mechanical pressure (also called press drying); thermal/vacuum drying (based on Lehtinen's idea for Condebelt drying) and impulse technology. Criteria used were: potential for cost reduction; potential for energy cost reduction; favourable influence on paper properties; extent of applicability; and ease of implementation [Sprague 1985].

report of May 1989 only empirical data based on platen press measurements were presented. This report indicated that problems with delaminating the sheet might hinder the development of impulse technology. IPC's optimism about the potential and commercial application of impulse technology, which was widely articulated during the late eighties, – *"Commercial application can be expected in the next few years" [Sprague and Lavery, 1988, p. B221]* – proved ill-founded.

### 1987-1989: Commercialisation?

Beloit, IPC and the US paper manufacturer Weyerhaeuser made a joint research effort from April 1987 till March 1988. The aim was to determine if and how impulse technology could improve the production output and product quality of an existing linerboard machine [Crouse et al., 1989]. Beloit and Weyerhaeuser had co-operated before in the successful innovation of the shoe press at Weyerhaeuser's Springfield mill in December 1980.

Sam Huston, Weyerhaeuser's vice president of container-board, who was involved in the introduction of the shoe press, served on IPC's research committee [Woo, 2000]. He was greatly interested in IPC's research on impulse technology and aware of Beloit's private R&D activities regarding impulse technology. His management position within Weyerhaeuser allowed him to get Weyerhaeuser involved in a joint impulse technology research effort. Huston was a big supporter of this effort [Bergström, 2000; Vance, 2000]. The three actors agreed to 'jump-start' impulse technology; it was thought to be relatively easy to feed a shoe press with heat [Orloff, 2000; Crouse, 2000; Woo, 2000].

In 1987, Beloit added an induction heater to the existing shoe press on Beloit's No. 2 pilot paper machine. Felt supplier Albany was involved in running felt trials [Crouse, 2000]. A complete series of trials was planned. However at the beginning of the trials, it became evident that the paper sheet delaminated. Whereas 'blistering of the paper sheet' had already been noticed by Wahren and Arenander back in 1983, it took these pilot machine experiments to show that this was a *'stumbling block'* [Crouse et al., 1989]. The only thing to be done was to determine the temperature above which delamination occurred, also called the critical temperature. The article closed with the statement that: *"When delamination was avoided by operating with surface temperatures of 150°C or lower, <u>true impulse drying</u> (transport of water driven by a steam gradient (EL)) must have been precluded. Under such operating conditions the benefits were not significantly different from those obtainable by conventional pressing using elevated sheet temperatures. Hence, to realise the potential of impulse drying, it will be necessary to alleviate delamination" [Crouse et al., 1989, p.215]*.

DOE was not aware of the joint venture between Beloit, IPC and Weyerhaeuser, until failure became apparent[9] [Sobczynski, 1998]. Weyerhaeuser lost interest in impulse technology, partly because of delamination but primarily because of the realisation

[9] According to Crouse (Beloit), the US Department of Energy was aware of IPC's impulse technology R&D activities with Beloit and Weyerhaeuser [Crouse, 2000].

that sheet strength did not increase substantially. The expected savings in raw materials were not achieved [Woo, 2001]. IPC and Beloit continued R&D activities, but independently.

### 1983-1994: R&D at Paprican – light-weight grades

In 1983, the Canadian national pulp and paper research institute Paprican started impulse technology R&D. The research was initiated by Paprican's president [Pikulik, 2000]. Impulse technology was seen as an important innovative technology that could increase sheet dryness and thus promised shorter drying sections, increased machine output and significant energy savings [Sparkes and Poirier, 1990a]. First a platen press was used. In 1985, a laboratory roll press was commissioned [Sparkes and Poirier, 1990b]. Paprican's activities focused on newsprint, a light-weight printing paper grade. Newsprint is an important grade in Canadian paper production[10]. The lab-scale research efforts were partly funded by the Canadian Electricity Association. Additional resources were generated by member dues [Pikulik, 1998].

Because of the dominance of newsprint production in Canada, the researchers at Paprican wanted to evaluate impulse technology for newsprint at commercial speeds. The tendency for heavier weight-grade to delaminate strengthened Paprican's preference for light-weight newsprint grades still further [Sparkes and Poirier, 1990a]. Paprican's existing pilot paper machine had to be rebuilt [Sparkes and Poirier, 1990b; Poirier and Sparkes, 1991].

Paprican applied to the Canadian government for financial support[11]. The Canadian government supported 45% of the costs for the rebuilding of the pilot paper machine on condition that a paper machine supplier and paper manufacturers were involved in the project. A further condition was that if the technology turned out to be successful, it should be implemented in Canada [CETC, 1999].

Beloit became involved as a machine supplier. The co-operation between Paprican and Beloit was initiated at a TAPPI Engineering conference in the middle of the 1980s. Busker (Beloit's Rockton lab) met Pikulik (Paprican) and suggested they should co-operate on light-weight grades rather than pursue R&D on these grades independently. When Paprican was looking for a machine supplier to be involved in the rebuilding of the pilot paper machine, Paprican approached Beloit. Beloit Canada supplied the equipment (making no profit) [Crouse, 2000; Pikulik, 2000].

It was interesting for Beloit's Rockton lab to co-operate with Paprican. Beloit did not have a pilot paper machine with two *heated* (shoe) press nips, which is important in

[10] 36% of the Canadian production is newsprint. There are 150 newsprint machines [CETC, 1999].

[11] Paprican applied to National Resources Canada. Financial support was granted under the Industry Energy Research and Development (IERD) programme, which is administered by CANMET Energy Technology Centre. IERD programme encourages and supports industry proposals for the development and application of leading edge, energy-efficient and environmentally responsible processes, products, systems and equipment. To encourage the widest possible application of the technologies developed the IERD programme strives to link technology developers and users, encourages the formation of research consortia and supports technology transfer [CETC, 1999].

order prevent two-sidedness of the light-weight sheets. Beloit's Rockton lab did not have the budget to install a second heated (shoe) press nip on one of its own pilot paper machines [Crouse, 2000; Orloff, 2000]. Albany was also involved [Pikulik, 1998; CETC, 1999].

R&D at Paprican finished in 1994. Most of Paprican's results were not published. Beloit and Paprican claimed to be ready to apply impulse technology to a commercial paper machine; delamination was not a critical problem for light-weight grades when the pilot machine was run under suitable process conditions [Pikulik et al., 1996].

Beloit used the experimental results to search for a newsprint manufacturer willing to commercialise impulse technology. They first asked Canadian newsprint manufacturers and then newsprint manufacturers around the world [MacGregor, 2000]. Commercialisation, however, never occurred. Lack of interest on the part of Canadian newsprint manufacturers was explained by the collapsed newsprint market situation in Canada; more important, however, was the general lack of experience with shoe press technology of newsprint manufacturers[12] [Pikulik, 1998; Crouse, 1998].

### 1989-1995: R&D at IPST – solving delamination for board grades. Part I

In 1989, the Institute of Paper Chemistry (IPC) moved to Atlanta. The institute was renamed the Institute of Paper Science and Technology (IPST). The move to Atlanta caused some researchers who had contributed substantially to impulse technology to leave the institute. David Orloff became principal investigator[13]. DOE continued to support IPST's impulse technology research. Orloff convinced Sobczynski that if delamination could be overcome it would not be very difficult to implement impulse technology on linerboard-machines; shoe presses were already widely used, 'only' a heater had to be added. [Orloff, 2000]. With Orloff guiding the impulse technology R&D the results of research were covered by patents [Orloff, 1997].

Orloff restricted the research to solving the delamination problem for linerboard. There were three reasons for looking at linerboard. First of all, Beloit had an agreement with Paprican to look at light-weight grades (< 80 g/m$^2$). IPST would look at heavier-weight grades (> 80 g/m$^2$) [Orloff, 1200; Pikulik, 2000]. Secondly, linerboard is an important grade in the US and the introduction of the shoe press for this grade was a success. Finally, impulse technology was likely to enhance the strength properties of linerboard [Lavery, 1988; Orloff, 2000]. The laboratory platen press was heavily used again. It was easier to use and generated many more data in a shorter time than the laboratory roll press [Orloff, 2000].

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[12] The first single shoe press was installed on a newsprint machine in 1994. Impulse technology required not one but two *heated* shoe press nips. This was too big a step to take. Note that Paprican's pilot paper machine had only one shoe press nip. The second press nip was a large roll press. Beloit did not have a pilot paper machine with two shoe press nips.

[13] With Orloff leading the impulse technology R&D a series of IPST patents can be found regarding impulse technology (see [Orloff et al., 1992] till [Orloff et al., 1998]).

Researchers at IPST proposed that controlling the sheet temperature prior to opening the press nip could suppress delamination [Orloff, 1997]. A reduced sheet temperature would reduce the amount of water that flashes to vapour during nip opening. The heat transfer to the paper sheet needed to be controlled to prevent delamination. Research focused primarily on alternative roll surface materials, such as zirconium oxide coatings, which had a low thermal mass. Such ‘cermet’ coatings reduced heat transfer to the sheet, while maintaining high surface temperatures. Furnish variables such as the specific surface were also found to play a role in delamination [Orloff and Sobczynski, 1993; Orloff, 1994; Orloff, 1997]. Lab press experiments showed that a cermet coated roll made it possible to increase temperature during wet pressing and prevent sheet delamination [Orloff, 1992a; Orloff, 1992b]. IPST co-operated with a firm that was specialised in such coatings, Fisher-Barton [Orloff, 1989]. In 1991, the laboratory roll press was used for studies of roll coating durability [Orloff et al., 1995; Orloff, 2000].
Between 1988 and 1992, Beloit and IPC formally did not co-operate regarding impulse technology R&D. Contacts at the management level were minimised. In spite of this, Orloff continued to visit Beloit now and then [Orloff, 1997; Crouse, 1998]. Beloit’s private activities focused primarily on light-weight grades. Beloit’s activities in linerboard, however, were never stopped completely [Crouse, 1998; Orloff, 2000].
During 1992, IPST and Beloit started to work together again [Orloff and Lindsay, 1993]. During 1993, Beloit’s heated shoe press on the No. 2 pilot paper machine was used for experiments with the cermet coated rolls. In 1993, Beloit started to co-operate with Fisher-Barton (just as IPST) to test different coating materials [Orloff, 2000].

During 1992, IPST announced their ‘plan for the commercialisation of impulse technology’. IPST felt ready to prove the potential of impulse technology on a pilot paper machine. This step had to be made in order to interest paper manufacturers in applying impulse technology on a commercial scale (see [Orloff, 1992c; Orloff and Sobczynski, 1993; Orloff and Lindsay, 1993]). DOE was again asked for support. DOE was willing to support the commercialisation of impulse technology on condition that both a machine supplier and a paper company were involved [Sobczynski, 1998; Orloff, 1997]. In December 1993, Orloff and Sobczynski together announced that commercialisation of the technology would be undertaken by a consortium composed of IPST, its member companies, a machine supplier and DOE. At that moment innovation was expected in 1997-98 [Orloff and Sobczynski, 1993].
High level representatives of IPST’s member companies were invited to a meeting at IPST. Different member companies had different machine suppliers; some had Beloit machines, some had Voith machines, and others had Escher Wyss machines. Therefore, IPST was asked to contact all major machine suppliers to see who was willing to commercialise impulse technology. Only Beloit responded. The achievements that IPST had made in controlling delamination for heavy- weight

grades were a good reason for Beloit to look at heavier-weight grades again [Crouse, 1998; Orloff, 1997]. Beloit's Larry Chance, who had become vice-president of the Rockton lab after Bergström left in 1984, attended the meetings [Orloff, 2000]. A series of monthly meetings was organised for over half a year. Total commercialisation costs were estimated to be 20 million US$ [Orloff, 1997]. Only Union Camp expressed interest. Weyerhaeuser showed very little interest; their former experience had made them shy. There were serious negotiations between Beloit and IPST and Union Camp and Beloit. IPST would receive royalties for the patents they licensed to Beloit. Union Camp also wanted royalties on future sales to compensate them for running the risk of being the first in the field. Beloit agreed to the IPST royalty agreement but Beloit and Union Camp could not come to terms [Orloff, 2000; Robinson, 1998].
When it turned out that none of the US linerboard manufacturers was willing to join, DOE agreed to support a consortium of Beloit and IPST. DOE really wanted the technology to become a success [Pikulik, 1998; Crouse, 1998; Orloff, 2000]. Or in Sobczynski's own words: *"Most important to him (Sobczynski) and DOE was that the US industry would benefit first from the new technology and would be able to get options at reduced costs, based on the heavy subsidies by DOE. If IPST would have continued co-operation with a foreign machine supplier, Sobczynski would also have tried to warrant R&D support for the pilot machine R&D activities" [Sobczynski, 1998]*. The aim of the joint effort was to build an impulse press nip on Beloit's newly built No. 4 pilot paper machines and to show its viability. The new pilot paper machine No. 4 was a light-weight paper machine, although it could be used to produce linerboard. However, making the pilot paper machine appropriate for impulse technology was not the major reason why the pilot paper machine was built in the first place. Crouse had to make sure that any equipment changes made for impulse technology would not negatively impact on the primary mission of the new pilot paper machine: attracting customers to improve Beloit's bad business situation at the time. Before the agreement between Beloit, IPST and DOE was signed, there were obstacles within Beloit that had to be overcome. The most important was to show that the cermet coated rolls were also suitable for low temperature wet pressing. Without such rolls on the pilot paper machine, it would have been almost impossible to get machine time for impulse technology trials [Orloff, 2000]. IPST's patents were licensed to Beloit. Late in 1995, when the implementation of the impulse press nip started the project was expected to end in June 1997 [Orloff, 1997; Sobczynski, 1998].

Meanwhile, Beloit continued to use the laboratory heated roll press for running impulse tests at the request of Beloit's customers. The sheet was made at Beloit's No. 3 pilot paper machine and then impulse dried on the lab roll press. Such trials kept industry's interest high [Crouse, 2000].

### 1995-1999: R&D at IPST – solving delamination for board grades. PartII

During the winter of 1993/94, Orloff had access to Beloit's No.2 pilot paper machine to do some testing. He became increasingly aware that 'post-nip' modifications were required to control delamination of linerboard [Orloff, 2000; Orloff et al., 1995]. Improvements 'in' the press nip (like e.g. the cermet coatings) were not the entire answer. From 1994 onwards, researchers at IPST focused on 'post-nip' modifications [Orloff, 1997].

Babinski and Mumford, who were doing some impulse technology R&D at the R&D lab of International Paper[14], hypothesised that delamination could be reduced by exposing the paper sheet to a pressurised steam environment at its exit from the impulse press nip. Orloff followed this idea and suggested a 'gas chamber' instead. The external gas pressure balances the pressure inside the paper sheet and holds the sheet together while the internal pressure decays [Orloff et al., 1997d; Orloff and Crouse, 1999]. The old laboratory platen press was converted and experiments were done. IPST's membership finances were spent on these experiments so that the results could be kept secret. Until the moment IPST filed the first patent in May 1995, nobody was told the details of these developments [Sobczynski, 1998; Orloff, 2000]. Later, an external mechanical force to guarantee counter pressure that prevented the flashing to steam was patented [Orloff et al., 1997e]. In 1997, the first laboratory results of post-nip control of delamination were presented at the TAPPI Engineering Conference (see [Orloff et al, 1997a; Orloff et al, 1997b; Orloff et al. 1997c]).

IPST's patents were again licensed to Beloit. Beloit paid to get international patent protection [Orloff, 1997]. To show that the concept was not just a laboratory curiosity, the equipment to control decompression and thus delamination during nip opening was implemented on Beloit's No. 2 pilot paper machine in 1997. Experiments were done during the summer of 1997 and winter of 1998 [Orloff and Crouse, 1999]. Early in 1998, Beloit's new No. 4 pilot paper machine was also supplied with the additional post-nip equipment. The first impulse experiments using the No. 4 pilot paper machine were run during the summer of 1998. For the first time, impulse pressed paper was formed, pressed, dried and reeled in one continuous operation [James, 1999]. A number of container-board manufacturers were contacted in order to find one who was willing to convert impulse dried linerboard into corrugated boxes. It took time but eventually Stone Container was interested [Orloff, 1998]. Quality measurements were performed (see [Orloff et al., 1999b]).

The results were presented at the TAPPI Engineering Conference in 1999 (see [Orloff et al., 1999a; Orloff et al., 1999b]). Impulse technology increased paper sheet dryness by 3.3 to 4%. Strength property improved 15 to 20%. Energy costs, however,

[14] International Paper is a large US paper manufacturer and was not a member of IPST. International Paper is one of the US paper manufacturers with a large and established R&D department. International Paper performed some impulse technology R&D to explore the advantages of impulse technology on paper properties (see e.g. [Babinski and Mumford, 1995]). The R&D was stopped because Condebelt was considered to have greater potential and International Paper's R&D strategy moved more towards product-oriented R&D than process-oriented R&D [Orloff, 2000].

increased due to the use of electricity [Orloff et al., 1999a]. Tests with the boxes showed that impulse technology can be used to reduce fibre usage by about 10% while maintaining strength properties [James, 1999].
Since then, IPST and Beloit have been sharing their research data with linerboard manufacturers. They hoped to identify an appropriate candidate for the first commercial installation of impulse drying [Orloff, 1997; James, 1999].

In 1998, Orloff gave a presentation at the annual member conference about four of IPST's major R&D projects. Impulse technology was one of them. Orloff's message was that there was no role left for IPST in these R&D projects [Sobczynski, 1998; Orloff, 2000]. Impulse technology R&D at IPST was stopped in 1999. IPST had committed themselves to showing the feasibility of impulse technology via a pilot paper machine. This plan was supported by the member companies and was actually realised. By then, impulse technology had become the task of the machine supplier[15] [Orloff, 2000].

Beloit's attempt to commercialise impulse technology came to an abrupt end when Beloit's mother company filed for bankruptcy in 1999. The Rockton lab was closed in 2000. The Finnish machine supplier Valmet bought the rights to Beloit's patents and Beloit's new pilot paper machine No. 4 was shipped to Finland[16] [Crouse, 2000; Orloff, 2000]

### Late eighties – now: R&D in Europe

During the late 1980s, interest in impulse technology arose in Europe due to the research results presented by IPC and Paprican [Talja, 2000; Boström, 2000]. By that time, the shoe press had become a proven technology and it was clear that impulse technology would benefit from the longer nip residence time in a shoe press nip [Backström, 2000; Hollmark, 2000].

In 1988, the Finnish machine supplier Valmet started R&D. High dryness and improved paper properties were the arguments put forward for exploring impulse technology. Valmet was also involved in a co-operative project with the Finnish national pulp and paper research institute KCL and Tamfelt, a Finnish felt supplier. This project was supported by the Technology Development Centre of Finland (TEKES) [Paulapuro, 1991; Talja, 2000]. In 1990, the results induced Valmet to conclude that uncertainties were still too high to seriously pursue further development [Talja et al., 1991]. R&D was put on hold. The further development of impulse technology was monitored by publications and patents [Talja, 2000].

15 As a spin-off of the development of impulse technology for wet pressing, commercialisation of impulse technology for paper sludge drying is being pursued collaboratively by Ashbrook Corporation and IPST [Orloff, 1997; Mahmood et al., 1998].
16 Talja (Valmet) is not willing to comment on this topic [Talja, 2000].

The former head of Beloit's Rockton lab, Bergström, was working at the Swedish national pulp and paper research institute STFI. He was the first to make plans to equip STFI's pilot paper machine with two impulse press nips in 1986/87. STFI was not willing to invest; other projects had priority [Bergström, 2000].

Fastmark, who worked at the Swedish Organisation for Technological Development (NUTEK), had become aware that impulse technology was a high-risk energy-efficient technology [Norman, 2000; Fastmark, 2000]. He was familiar with impulse R&D activities in the US and Canada because of his contacts within the International Energy Agency's Implementing Agreement on pulp and paper[17]. In 1988, Fastmark contacted the researchers at STFI and KTH to interest them in starting impulse technology R&D in Sweden [Norman, 2000; Bäckström, 200; Fastmark, 2000]. Commissioned by NUTEK, Lund University (LTH) made a literature review of innovative pressing and drying technologies, one of them being impulse technology [Stenström, 1989]. In January 1990, Fastmark had a meeting with representatives of the Swedish pulp and paper research institutes. His message was that if a proposal on impulse technology R&D using STFI's pilot paper machine were to be submitted, NUTEK would seriously consider supporting it from the Energy budget[18] [Fastmark, 2000; Norman, 2000].

In 1991, NUTEK supported a feasibility study at STFI [Bergström, 2000; Fastmark, 2000]. In 1992, NUTEK agreed to designate a budget for impulse technology R&D. However, the budget was too small to rebuild STFI's pilot paper machine. The plans to start R&D on impulse technology were delayed [Fastmark, 2000; Hollmark, 2000].

It took STFI until 1996 to submit a definitive proposal. Time was needed to gather additional external financial resources for rebuilding the pilot paper machine. NUTEK had promised a contribution of roughly 40% and the Swedish paper manufacturers were reluctant to invest in a rebuild [Backström, 2000; Hollmark, 2000]. STFI continued to strive for impulse technology R&D because NUTEK's offer of financial support propitiously coincided with STFI's wish to modernise the wet pressing section of the pilot paper machine [MacGregor, 2000; Norman, 2000; Bergström, 2000]. Furthermore, STFI was engaged in a re-organisation to reinforce its position as a leading pulp and paper research institute: impulse technology R&D was a large and visible 'high risk' project [Bergström, 2000; MacGregor, 2000;

[17] The International Energy Agency (IEA) stimulates the development and use of new and improved energy technologies in order to achieve energy security, environmental protection and economic and social development. The IEA's R&D collaboration programme facilitates R&D co-operation among IEA member and non-member countries. The idea behind the R&D collaboration programme is that national energy R&D should become more effective and efficient when incorporated into the larger context of international R&D activities. Co-operative activities regarding specific themes are set up under 'Implementing Agreements'. There is an Implementing Agreement on efficient energy use in the pulp and paper industry (1981). Members of this Implementing Agreement co-operate in pre-competitive R&D on specific technologies or concepts.

[18] The Swedish government had allocated a substantial budget to the Energy Programme in order to phase out nuclear energy. Improving the energy efficiency of energy intensive industries was one of the areas of attention. Research institutes and other actors could seek support from the Energy budget for both R&D and equipment building [Fastmark, 2000].

Wahren, 2000]. The idea of starting a 'high-risk' R&D programme attracted external support for the rebuilding of the pilot paper machine [Norman, 2000; Bäckström, 2000; Fastmark, 2000; Hollmark, 2000]. Both Hollmark, group leader of STFI's paper process group, and Alsholm, STFI's president, played a crucial role in bringing the plan to fruition[19] [MacGregor, 2000; Backström, 2000; Norman, 2000; Wahren, 2000].

In 1995, the major machine suppliers were asked to quote a price. Voith showed no interest. Beloit did not respond. Valmet's offer was best. By that time Valmet had also become a member of STFI (1995) [Hollmark, 2000; MacGregor, 2000]. During 1995, STFI and Valmet developed concrete plans to rebuild the pilot paper machine [Talja, 2000]. STFI's pilot paper machine was inaugurated in October 1997 by the King of Sweden. A 3-year research programme was launched as one of STFI's 'major R&D programmes' [STFI, 1998]. A second 3-year research programme started in 2000 [Bäckström, 2000]. NUTEK supported 40% of the programme [Fastmark, 2000; Bäckström, 2000]. The additional 60% is being financed by a limited number of member firms such as Valmet-Karlstad, Albany Nordiskafelt, and some paper manufacturers [Boström, 1997]. Valmet-Karlstad contributes man hours in machine construction and design issues [Talja, 2000]. The research results are only available to these member firms [STFI, 2000].

In addition to its major R&D programme, STFI initiated a Joule project which focuses on more fundamental aspects of impulse technology[20] [Backström, 2000; Norman, 2000]. STFI co-operates closely with Swedish universities like KTH and LTH [Bäckström, 2000; Stenström, 2000; Bergström, 2000]. Whereas STFI stated recently that there might be a dewatering mechanism involving steam-assisted water removal, a recent thesis at LTH cast doubts on the water removal mechanism claimed by Wahren (see [Rigdahl et al., 1999; Larsson, 1999]).

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[19] Hollmark left STFI for SCA soon after that the research programme had started. Patents reveal that he is involved in impulse technology related activities at the research lab of the Swedish hygienic paper manufacturer SCA (see e.g. [Billgren et al., 2000; Kaveh et al., 2000]). SCA was a member of STFI till 2000. They supported STFI's impulse programme between 1997 and 2000. SCA performed private R&D activities using STFI's pilot paper machine [Orloff, 2000; MacGregor, 2000; Bäckström, 2000].

[20] The Joule programme is part of the Framework Programme of the European Commission. One of the priority areas within Joule is the rational use of energy in industry. The title of STFI's project: High temperature pressing of fibrous materials (JOU3-970078 / January 1998 - December 2000). Actors involved: STFI, LTH, KTH, Valmet-Karlstad, Albany Nordiskafelt, University of Porto and the French National Polytechnic of Grenoble (EFPG). A large number of these actors, STFI, LTH, KTH and EFPG, were also involved in an earlier JOULE project. Title of project: Establishing the scientific base for energy efficiency in emerging pressing and drying technologies (JOU2-20041 / January 19993 – December 1995). The work in this project was oriented mainly towards wet pressing [Vincent, 1997].

There is some additional impulse R&D going on in Europe. STFI co-operated with TNO in the Netherlands on modelling impulse technology [Riepen, 1998]. The Dutch Novem also supported a project to summarise the state of the art (see [Van Lieshout, 1998]). Helsinki University of Technology (HUT) started a small project on impulse technology in October 1996 in which HUT co-operated with IPST. The entire project was supported by the Technological Development Centre of Finland (TEKES) [Paltakari, 2000].

### IEA Implementing agreement on the pulp and paper industry

At a meeting in 1995, the representatives of Finland and Sweden suggested impulse technology as an Annex to the IEA Implementing Agreement. By 1997, the details of this Annex had still not been finished and the R&D tasks had still not been defined [Boström, 1997]. In 1998, Vikram Kaul (STFI) was given the mandate to negotiate with the key players (being Paprican, IPST, Beloit and STFI) on pre-competitive co-operative R&D tasks. No consensus could be reached, because of the proprietary character of impulse technology R&D [Orloff, 1997; Boström, 2000; Riepen, 1998]. The Implementing Agreement did completely abandon impulse technology; the focus was expanded to ‘advanced dewatering technologies’. The competitive atmosphere relaxed, some tasks were identified, although financial resources are still lacking [Boström, 2000; Orloff, 2000].

### The other major machine suppliers

Two other major machine suppliers, the German firms Escher Wyss and Voith, performed some laboratory experiments regarding impulse technology. Escher Wyss stopped these activities in 1993 because there were too many critical problems to be solved. The investment required both financially and in man-years was too large [Mirsberger, 2000]. Voith did not see a clear future for the technology because impulse technology severely damaged the paper sheet. The potential advantages of impulse technology were too small to justify the R&D effort that was needed to overcome these problems [Schiel et al., 2000]. When Voith and Escher Wyss merged in 1994, impulse technology was discussed when the R&D facilities were merged and priorities in research were integrated and redefined. Researchers from both firms agreed on the problems they had faced in earlier research activities and it was decided not to spend money on impulse technology but to wait and see what would result from the ongoing R&D activities [Mirsberger, 2000].

## 4.4. Analysing the development

In this section we will analyse the technological development of impulse technology using a set of questions that focus on the technology network, the various micro-networks and the materialisation of the technology. We first deal with the questions relating to the 'technology network'. A technology network usually consists of a number of smaller micro-networks in which a few actors co-operate. We subsequently focus on some questions concerning the micro-networks. Finally we explicitly comment on the materialisation of the technology so far and the role of performance characteristics in guiding actors' activities. The role and arguments of government will be discussed separately in Section 4.5.

## Technology network

What is the composition of the technology network?

Figure 3 gives a summary of the development of impulse technology since 1970.

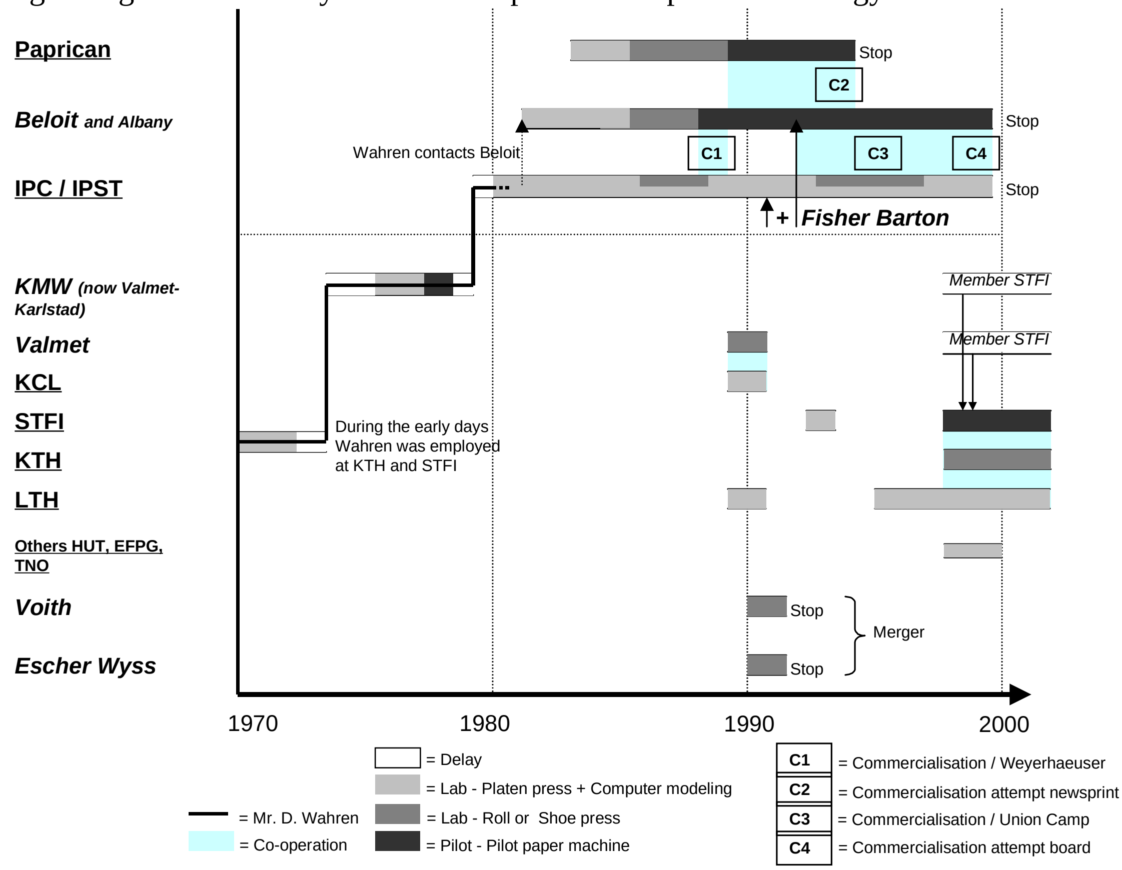


*Figure 3: Technology network of impulse technology. The size of the R&D equipment used – laboratory platen press, laboratory roll press, pilot paper machine – indicates the up-scaling of the technology. Actors in ordinary letters are paper manufacturers. Actors in italics are machine or felt suppliers. Actors with underlining are research institutes. IPC/IPST, Paprican, KCL and STFI are four national pulp and paper research institutes which are partly supported by national paper and board manufacturers.*

The development of the technology network can be divided into three stages (see Figure 3). From 1970 to 1980, R&D activities were performed by one man, the inventor of the technology. Wahren shelved his idea twice before he succeeded in anchoring and extending R&D activities at the US national pulp and paper research institute. Between 1980 and 1990, a North American micro-network emerged. From 1990 onwards, R&D activities were initiated in Europe. Just one micro-network resulted, STFI's. Voith and Escher Wyss did not continue. In the year 2000, only STFI's micro-network was still active.
Although it is a simplification we make a distinction between two micro-networks: the North American micro-network and STFI's micro-network. Within the North American micro-network IPST and Paprican did not co-operate closely. They were aware of each other's activities and they agreed to focus on different grades, but Beloit is the only connection between these two actors. The R&D activities in Europe are headed by STFI's micro-network because since 1997 STFI has been the pivot in the European R&D activities [Talja, 2000].

Figure 3 shows that the development of impulse technology is an international activity, although actual research activities are undertaken at a restricted number of places. The technology network shows the names of four (by now two) major machine suppliers and the names of established national pulp and paper research institutes [Eriksson, 1997]. The technology network consists mainly of the traditionally known and important actors that perform R&D for the benefit of the paper industry.

<u>To what extent and how often do micro-networks exchange knowledge/information?</u>

Contacts within micro-networks have been more frequent and more intense than contacts between micro-networks. This is not surprising. First of all, Beloit and Valmet were competitors. Secondly, the various national pulp and paper research institutes are tied to their member companies. They are also competitors [Wahren, 1998; Talja, 2000]. This is highly visible in the North American micro-network; IPST and Paprican did not co-operate [Orloff, 2000; Pikulik, 1998]. Whereas representatives of these national pulp and paper research institutes visited each other and 'talked to each other' (see e.g. [Vomhoff, 1995]), they all behaved according to the unwritten but well understood rules of confidentiality [Pikulik, 2000]. There have been co-operative R&D activities 'across' the North Atlantic although not between two national pulp and paper research institutes; IPST co-operated with a Finnish University (HUT) and someone from a Swedish university (LTH) visited IPST.
Patents are generally used as a source of information to monitor what other competing actors are doing [Orloff, 2000; Crouse, 1998; Talja, 2000].

Are there dominant micro-networks in the technology network?

In the technology network, neither of the two micro-networks had a continuing decisive influence on the development of the technology. However, there have more ‘dominant’ actors in the course of time.
The inventor of the technology dominated during the first 10 years. Wahren took the idea with him. He did not talk about it until he ran pilot paper machine trials and protected his idea with a patent [Wahren, 1998]. From 1985 till the demise of the North American micro-network (1999), Beloit was generally regarded as the dominant actor; during those days that firm was the only actor that had a lot of (unpublished) pilot paper machine data at its disposal. Because Beloit’s activity came to a halt, another micro-network came to the fore. STFI (with Valmet at the background) is the only actor left who seriously invests in the development impulse technology. Valmet is not performing private R&D, but they acquired Beloit’s assets in impulse technology (patents and pilot paper machinery).

## Micro-networks

How are the various micro-networks made up?

Figure 3 shows what types of actors played a role in the two micro-networks. The two micro-networks show large similarities. First of all, national pulp and paper research institutes played an initiating role and they performed a substantial part of the R&D activities.
Secondly, machine suppliers were involved in both micro-networks. Whereas Beloit performed substantial private R&D activities, Valmet is not performing private R&D itself. Valmet is involved as a member of STFI’s R&D programme, although the technology is still considered to be too uncertain to develop it privately [Talja, 2000; Talja, 1991].
Thirdly, in both micro-networks paper manufacturers were passively present (as members of the national pulp and paper research institutes). Paper manufacturers showed up actively when innovation appeared to be just around the corner (see Figure 3, [C1] and [C3]). This role of paper manufacturers is rather ‘typical’ in the development of process technologies [Philips, 2000]. However, there were some exceptions to this stereotyped role. Orloff was inspired by a suggestion of Babinski and Mumford, who worked at International Paper [Orloff, 2000]. Hollmark (who played a role in initiating the impulse R&D programme at STFI) performed R&D at SCA in Sweden [Bäckström, 2000; Hollmark, 2000]. Furthermore, one should not forget that machine suppliers are in contact with customers during the development of a new technology. At Beloit, the ongoing interest of paper manufacturers in running laboratory experiments stimulated the continuation of impulse technology R&D at Beloit [Crouse, 2000].

Specific individuals and contacts among persons at different firms or research institutes have been important in initiating and continuing R&D activities within micro-networks [Orloff, 1997; Sobczynski, 1998; Crouse, 1998; Backström, 2000; MacGregor, 2000].

What motivates actors to start and / or stop R&D activities?

Table 1 gives an overview of actors' arguments for starting R&D activities.

*Table 1: Arguments for starting the development of impulse technology.*

| | **Actor** | **Time** | **Improved dryness → reduced capital intensity** | **Improved dryness → increased machine speed** | **Increased dryness → improved energy efficiency** | **High risk technology with exposure** | **Paper properties (surface and mechanical properties)** |
|---|---|---|---|---|---|---|---|
| Wahren | Wahren (STFI / KTH) | early 1970s | • | | | | |
| | Wahren (KMW) | 1976 | • | | | | |
| Research institute | IPC / IPST | early 1980s | • | • | • | • | |
| | Paprican | 1983 | • | • | • | | |
| | STFI | 1997 | • | • | • | • | • |
| Machine supplier | Beloit | 1981 | • | • | | | |
| | Valmet | 1989 | • | • | | | |
| | | 1997[1] | • | • | | | • |
| | Escher Wyss | ~ 1990 | • | • | | | • |
| | Voith | ~ 1990 | • | • | | | • |
| Paper maker | Weyerhaeuser [C1] | 1987 | | • | | | • |
| | Union Camp [C3] | 1994 | | • | | | • |
| Govt. R&D support | US Department of Energy | 1985 | | | • | • | |
| | National Resources Canada | 1988 | | | • | • | |
| | NUTEK | 1989 / 1996 | | | • | • | |

[1] Valmet is involved in STFI's major R&D programme on impulse technology (member dues). After R&D programme is finished, Valmet can reconsider its role in developing impulse technology.

Table 1 illustrates that the new dewatering mechanisms impulse technology appealed to both machine suppliers and national pulp and paper research institutes. Although the research institutes stated explicitly that energy efficiency was a major argument for engaging in impulse R&D, the decisive arguments were in fact the increased machine speed and reduced capital intensity that would result from the new technology. As time went on, paper properties were increasingly mentioned as the most attractive characteristic of impulse technology.

Table 2 gives an overview of actors' arguments for ceasing to play an active role in developing impulse technology. Table 2 also includes the reasons why the four attempts for commercialising impulse technology had failed (so far).

*Table 2: Arguments for stopping the development of impulse technology.*

| | Actor | Time | Lack of financial resources and personal capacity | Strategic business decision or stop business activity | R&D completed | Lack of experience with shoe press | Major uncertainties in performance |
|---|---|---|---|---|---|---|---|
| Wahren | Wahren (STFI / KTH) | 1973 | • | | | | |
| | Wahren (KMW) | 1978 | | • | | | |
| Research institute | IPC / IPST | 1999 | | | • | | |
| | Paprican | 1994 | | | • | | |
| | STFI | still active | | | | | |
| Machine supplier | Beloit | 1999 | | • | | | |
| | Valmet | 1990 | | | | | • |
| | | still active | | | | | |
| | Escher Wyss | ~ 1990 | | | | | • |
| | Voith | ~ 1990 | | | | | • |
| Paper maker | Weyerhaeuser [C1] | 1989 | | | | | • [1] |
| | Newsprint [C2] | 1994 | | | | • | • |
| | Union Camp [C3] | 1995 | | | | | • |
| | Board [C4] | 1999 | | | | | • [2] |

[1] Weyerhaeuser lost interest because there was no improvement in the strength of heavy-weight. Delamination hampered further commercialisation [Woo, 2001]. [2] Beloit and Union Camp did not agree on the financial terms to cover Union Camp's risk in the 3-partite attempt to achieve commercialisation. DOE had granted support for commercialisation.

In the early 1990s, the uncertainties (and thus business risks) were too high for three of the four major machine suppliers to continue private R&D (see Table 2). Only Beloit continued its R&D activities. There was scepticism within Beloit regarding the feasibility of impulse technology, especially after the failed commercialisation attempt in 1987-89 (with Weyerhaeuser, [C1]) and 1994 (after ending R&D activities with Paprican [C2]). However, management permitted Jere Crouse to continue R&D as a high-risk project for a relatively small investment [Crouse, 2000; Orloff, 2000; Busker, 2000; Sobzcynski, 1998]. Beloit's R&D activities came to an end when its mother firm filed for bankruptcy.

Table 2 indicates that two of the three national pulp and paper research institutes finished their R&D activities when they succeeded in bringing the technology to the stage to which they had committed themselves (and they were supported to by their member firms). In both cases, other R&D projects took priority [Pikulik, 1998; Orloff, 2000].

How much money is spent and by whom?

Table 3 summarises the expenditure on impulse technology R&D by the two micro-networks (figures based on available data).

*Table 3: R&D expenditure and government R&D support.*

| MN | Actor | Period | Total [M US$] | Gov. support [M US$] | % | Government R&D support granted by: |
|---|---|---|---|---|---|---|
| North American | IPC/IPST | 1984 –1996 | [1]5.8 | [1]3.3 | 60 | US Department of Energy |
| | | | | [1]0.6 | 10 | Electrical Power Research Institute and US paper association AF&PA |
| | | 1996 –1999 | [2]1.3 - 1.5 | [1]0.9 | 60-70 | US Department of Energy |
| | Paprican | 1983 –1988 | n.a. | n.a. | | Partly funded by Canadian Electricity Association |
| | | 1988 –1994 | [3]8.0 | 3.6 | 45 | National Resources Canada |
| | Beloit | 1981 –1996 | [4]several millions | - | - | |
| | | 1996 –1999 | [1]1.5 | [1]1.0 | 66 | US Department of Energy |
| STFI | STFI | Rebuild PPM | [5]4.8 | [5]1.8 | 37.5 | NUTEK |
| | | | | 2.4 | 50 | Wallenberg Foundation (and Elforsk) |
| | | 1997-2002? | [5]~ 10 | [5]~4 | 40 | NUTEK |
| | | | n.a. | n.a. | n.a | Joule / European Commission |
| | Valmet | | [6]n.a. | - | - | |
| | LTH | | [7]< 0.5 | n.a. | n.a. | Partly supported through NUTEK and Joule / European Commission |
| | KTH | | [8] 0.2 | 0.1 | ~50 | Partly supported through Joule / European Commission |
| | KCL | 1990/91 | n.a. | n.a. | n.a. | Technology Development Centre Finland TEKES |
| | HUT | 1996/97 | [9]0.035 | 0.035 | 100 | Technology Development Centre Finland TEKES |
| Total | | | 32 | 14 | | Government R&D support |
| | | | | 3 | | Other external support |
| Total estimate | | | 35-40 | 15 | 40 - 45 | Government R&D support |
| | | | | 3 | 5 – 10 | Other external support |

[1] [Robinson, 1998; Fleischman, 2000]. [2] Estimate based on [Fleischman, 2000; Orloff, 1997]. IPST's member dues spent on impulse technology: 2.5 to 3.0 million US$ [Orloff, 2000]. [3] [CETC, 1999]. [4] Only rough expenditure available for entire time period [Crouse, 1998]. [5] The finance relating to impulse technology R&D for 2002 is not clear yet [Fastmark, 2000; Bäckström, 2000]. [6] Not willing to give an estimate [Talja, 2000]. [7] Own estimate. [8] [Norman, 2000]. [9] [Paltakari, 2000].

Table 3 shows that most of the total expenditure goes on research and development work at three national pulp and paper research institutes (80 to 90%) and at Beloit (5 to 10%). Government contribution is 40 to 45% of the total expenditure. Other external supporters are responsible for 5 to 10% of the total expenditure.

It is interesting to note that in the US, Canada and Sweden, the research institutes of the electricity utilities made a contribution to the development of impulse technology because it will increase the use of electricity in paper-making.

The data in Table 3 give an indication of the differences in the cost of laboratory presses and pilot paper machines. The cost ratio is 1 to 20-30. We estimate that a commercial impulse press nip is 2 to 3 times more expensive than the nip in the pilot paper machine.

<u>What important decisions are made with regard to the direction of technological development?</u>

Various national pulp and paper research institutes focused their R&D activities on various paper grades. In North America, the major reason for preferring a specific grade was the commercial importance of that grade in the institute's country. There was also an agreement to spread the R&D activities over different grades [Pikulik, 2000; Orloff, 2000].

## Materialisation

<u>What is the rate of development and what steps in up-scaling can be distinguished?</u>

It took more than 25 years for impulse technology to reach the stage it has reached today. Figure 3 shows that laboratory presses are still being used in addition to pilot paper machines. Figure 3 shows that Wahren started to use a pilot paper machine in 1978 [Wahren, 1998]; Beloit in 1987 (No. 2) and 1995 (No. 4); Paprican in 1989 and STFI in 1997. They all rebuilt existing pilot paper machines. IPST did not have a pilot paper machine at its disposal and thus depended on other actors for R&D activities on the pilot scale [Sobczynski, 1998; Crouse, 1998; Orloff, 2000].
Wahren, Beloit and Paprican needed 5 to 6 years to start pilot paper machine testing (see Figure 3). STFI skipped the laboratory scale R&D activities; but the Swedish universities LTH and KTH are closely co-operating with STFI. STFI did not inaugurate their pilot paper machine until 1997, because impulse technology R&D took off in Europe only after the first results were presented in North America. In addition, the shoe press had become a proven technology by then. Finally, it took STFI time to arrange external support for rebuilding the pilot paper machine [Talja, 2000; Hollmark, 2000; Backström, 2000; Norman, 2000; Fastmark, 2000].

Delamination is the major bottleneck that affected the materialisation of impulse technology. Although signs of delamination of the paper sheets were noticed during IPC/IPST's laboratory scale experiments (see e.g. [Arenander and Wahren, 1983]), the full impact of delamination first became apparent in Beloit's No. 2 pilot paper machine ([C1] in Figure 3). Delamination led to a continuous interest in laboratory presses (both platen presses and roll presses) as a relatively cheap and easy route to perform experiments [Pikulik, 1998; Crouse, 2000; Orloff, 2000]. Many methods have been suggested for controlling delamination (see Table 4).

*Table 4: Methods for preventing delamination [Larsson and Stenström, 1998; Orloff, 1997].*

| **Year** | **Source** | **Actor** | **Method** |
|---|---|---|---|
| 1989 | [Crouse et al., 1989] | Beloit and IPST | Use low basis weight |
| 1990 | [Stenström, 1990; Pulkowski et al., 1989; Pulkowski et al., 1992] | LTH<br>Beloit | Vapour flow should be made possible during contact in the press nip |
| 1992-94 | [Orloff, 1992a; Orloff, 1992b] | IPST | Decrease the heat flux |
| 1992-94 | [Boerner and Orloff, 1994; Orloff and Lindsay, 1992; Orloff, 1994] | IPST | Increase the permeability of the paper sheet |
| 1993-98 | [Orloff and Phelan, 1993; Larsson and Stenström, 1998; Orloff, 1997c] | IPST<br>Lund | Optimise pressure profile of shoe press |
| 1998 | [Larsson and Stenström, 1998] | Lund | Use peak pressure below the critical pressure |
| 1994-99 | [Orloff et al., 1997a; Orloff et al., 1997b; Orloff et al., 1997c; Orloff et al., 1999a] | IPST | Controlled depressurisation *after* leaving press nip (post-nip developments) |
| 2000 | [Nilsson and Norman, 2000] | KTH | Use a heated metal band |

A new way of tackling the delamination problem with heavy-weight grades was suggested by Orloff; post-nip developments were supposed to be needed to solve delamination for heavy-weight grades. So far STFI had not pursued this route. There is still no agreement on the best method for preventing delamination for different paper grades. Research results are even contradictory.

In addition to these R&D activities, one should bear in mind that the development of impulse technology did not occur in a vacuum. The introduction of the shoe press (in 1980 for heavy-weight grades and in 1994 for light-weight grades), the availability of new roll cover materials and the development of temperature resisting felts have all been important in the continued development of impulse technology [Crouse, 2000; Orloff, 2000].

Beloit's and Weyerhaeuser's success with the innovation of the shoe press made them eager to explore the commercial possibilities of impulse technology in 1987 (see [C1] in Figure 3). Their attempt failed due to delamination. Later attempts to commercialise impulse technology also failed; but this time it was because light-weight paper manufacturers were not yet familiar with shoe press technology (see [C2] in Figure 3).

What are the perceived performance characteristics of the technology?

The majority of the publicly available R&D results are based on laboratory-scale equipment, especially platen presses (see Table 4 and Table 5). The results of pilot machine experiments remain unpublished because of their proprietary nature.

Before discussing the changes in impulse technology's performance characteristics, we want to stress that it is difficult to extrapolate the research results from laboratory platen presses to a paper machine [Pikulik, 1998; Orloff, 1997]. Laboratory platen presses, laboratory roll presses and pilot paper machines differ in their geometry, which causes variation in stress distributions over the paper sheet [MacGregor, 1989]. A recent paper (see [Orloff and Larsson, 2000]) compares some laboratory platen measurements with the results based on pilot paper machine experiments. Whereas the trends in lab-scale experiments are generally observed in pilot scale experiments, the differences in actual measurements are considerable [Orloff and Larsson, 2000]. One should be aware of the uncertainties in such data when they are used to prove the future potential of the technology or when they are used in, for instance, bottom-up energy-efficiency studies (see e.g. [De Beer, 1998]).

The promise of impulse technology's dewatering capacity reported by Arenander and Wahren in 1983 was extraordinary. However, it appears that this promising performance characteristic gradually decreased as time passed [Orloff, 2000; Talja, 2000]. Table 5 and Table 6 give an overview of R&D results on dryness and energy use.

Table 5 clearly shows that the dryness decreases over time: the experimental results of Beloit's pilot paper machine (No. 4) are modest when compared to Wahren's original suggestions. Table 6 shows the wide ranges in the energy consumption data reported. The ranges show that the potential for improving 'industrial energy efficiency' during the development of impulse technology has been a constructed advantage rather than a proven fact. Now that *induction* heating systems are being used in the impulse press nip, energy savings have become questionable [Orloff, 2000; Crouse, 2000; MacGregor, 2000].
Both tables illustrate that Wahren's original hypothesis that impulse technology's dewatering capacity (and thus improved energy efficiency) could be attributed to a vapour front displacing liquid water is still controversial and is still being debated [Larsson, 1999; Rigdahl et al., 2000; Orloff, 2000; Talja, 2000].
Actors' arguments for investing in the development of impulse technology changed over time. Whereas Wahren emphasised the dewatering potential of impulse technology, the current focus trend is to stress that impulse technology's breakthrough will be motivated by improvements in paper properties instead of and increased dewatering capacity [MacGregor, 2000; Orloff, 2000; Crouse, 2000; Bäckström, 2000]. It is interesting to note that these are arguments that are likely to persuade government to support the development of impulse technology.

*Table 5: Improvements in dryness at the exit of the press nip*[1].

| **Source** | **Actor** | **Equip-ment** | **Grade [gr/m²]** | **Increase in dryness**[2] |
|---|---|---|---|---|
| [Arenander and Wahren, 1983] | IPC/IPST | Lab | 45 | 10 – 20 |
| [Lavery, 1988] | IPC/IPST | Lab | 125 - 205 | 10 – 20 |
| [Sparkes and Poirier, 1990a] | Paprican | Lab | 45 | 8 |
| [Orloff, 1992c] | IPST | Lab | 205 | 2 – 6 |
| [Orloff et al., 1995] | IPST | Lab | 205 | 3 – 8 |
| [Orloff and Crouse, 1999] | IPST and Beloit | Pilot | 126 | 4 – 13 |
| [Orloff et al., 1999a] | IPST and Beloit | Pilot | 160 | 3 – 4 |
| [Rigdahl et al., 2000] | STFI | Pilot | n.a. | No data reported |

[1] Various actors experimented with different paper grades. The increase in dryness differs between grades. In light-weight grades the increase in dryness is usually larger [Norman, 2000]. [2] In this column, we compare the increase in dryness with a *reference pressing technology*. The exact reference pressing technology differs among different sources. Sometimes 'conventional pressing technology' is taken as a reference, sometimes single felted or double felted wet pressing experiments on the equipment also used for impulse technology experiments are used as a reference.

*Table 6: Energy use per kg water removed in the impulse press nip. An impulse press nip will be inserted at the end of the wet pressing section to increase the dryness of the paper sheet at the entrance to the drying section. We thus compare the specific energy use in the impulse nip with the energy needed for evaporating a kg water in a modern drying section (about 3.000 – 3.500 kJ/kg $H_2O$) [Larsson, 1999; Van Lieshout, 1998].*

| **Source** | **Actor** | **Equipment** | **Energy use**[1] **[kJ/ kg $H_2O$]** |
|---|---|---|---|
| [Lavery, 1987b] | IPC/IPST | Lab | 1600 – 2300 |
| [Sprague, 1987] | IPC/IPST | Lab | 550 – 1400 |
| [Macklem and Pulkowski, 1988] | Beloit | Lab | 600 – 2000 |
| [Lavery, 1988] | IPC/IPST | Lab | 500 – 2300 |
| [Sprague, 1989] | IPC/IPST | Lab | 100 – 1500 |
| [Sparkes and Poirier, 1990a] | Paprican | Lab | 1500 |
| [Orloff and Sobzcynski, 1993] | IPST | Lab | 115 – 160 |
| [Phelan et al, 1996][2] | IPST | Lab | 200 – 800 |
| [Orloff et al, 1999a][3] | IPST and Beloit | Pilot (No. 4) | 1600 – 2000 |
| [Larsson, 1999][4] | LTH (STFI) | Pilot | 1300 – 3000 |
| [Norman, 2000] | KTH | Lab | 1300 – 2200 |

[1] Reported energy data are not given in *primary energy* units. Most laboratory-scale experiments do *not* include heat losses. Currently electrically heated systems are used. It is technologically feasible to use natural gas based heating systems, though induction based systems are preferred due to their high energy fluxes (see e.g. [Sparkes and Poirier, 1990a; Van Lieshout, 2000; Hollmark, 2000]. [2] Taken from [Larsson, 1999]. [3] Data derived from [Orloff et al., 1999a]. Beloit and IPST report that an 'energy penalty' is expected. The increase in strength improvements (and the reduced raw material costs) must outweigh the increase in costs of the electricity needed. Energy use per ton paper will increase when electricity is used to heat the shoe press: 170 kWh / ton paper (= 600 $MJ_e$) is needed to heat the shoe press. Increased dryness (4%) will lead to steam savings of roughly 450-600 MJsteam / ton paper [Orloff et al., 1999a]. [4] Data *including* heat losses in experimental testing [Larsson, 1999].

Beloit's state-of-the-art pilot paper machine No. 4 did not generate results that were convincing enough to persuade heavy-weight grade manufacturers to invest in the first commercial impulse press nip; the improvements in strength were not exciting enough to outweigh the energy penalty that was projected. Beloit and IPST did not find any customers interested in applying impulse technology on a commercial scale ([C4] in Figure 3) [Orloff, 2000; Crouse, 2000].

Some people are of the opinion that the current results should be valued at this moment in time[21]; it is generally agreed that further research is needed before impulse technology can be declared a complete success. The current pilot paper machines are considered to be the 'first generation' impulse presses only. Suggestions have yet been made with regard to 'second generation' impulse presses. The development of a 'super-elongated' nip should make it possible to control the pressure profile for a longer time; this should prevent delamination, increase dryness and improving paper properties such as strength (see e.g. [Larsson, 1999; Orloff and Larsson, 2000; Orloff, 2000]).

This task is primarily in the hands of STFI; their R&D programme is likely to continue till 2002. Valmet will co-operate and wait to see whether STFI's results are convincing enough to bring the technology to the market [Talja, 2000; Backström, 2000].

## 4.5. The effect of government R&D support

Now that we have analysed the historical development of impulse technology, we can focus our attention on the effect of government R&D support.

Table 3 shows that the financial R&D support given by government to IPST, Paprican and STFI (but also to other research institutes) has been substantial. The US Department of Energy (DOE) financed 60 to 65% of the total expenditure on impulse technology R&D activities in the US (not taking into account Beloit's expenditure between 1981 and 1995). The Canadian government supported 45% of impulse technology research at Paprican. The Swedish NUTEK supported STFI's impulse technology research activities substantially; paying 37.5% and 40% of the costs of rebuilding the pilot paper machine and the R&D programme, respectively.
All government support – from US, Canada, Sweden, Finland, the Netherlands and the European Commission – comes from budgets for industrial energy efficiency.

[21] Orloff claims that if the introduction of the cermet roll at Beloit's No. 4 pilot paper machine had gone more smoothly and if a 20 inch shoe press had been installed instead of a 12 inch shoe press, results would have been more promising that they are now. Or in Crouse's words (Beloit): *"The closed extended nip press (or shoe press) limited the length of the shoe so that a 40 ms nip could not be built. Therefore we could not build a 20 inch shoe that could achieve the high strengths everyone was looking for" [Crouse, 2000]*.

Government support was generally justified on the grounds that impulse technology is a 'high-risk energy-efficient technology' [Robinson, 1998; Sobczynski, 1998; Pikulik, 1998; Fleischman, 1998; Fastmark, 2000; CETC, 1999; Paltakari, 2000; Orloff, 1997]. The interest in impulse technology within the IEA is also explained by the technology's claimed energy efficiency [Boström, 1997].

Our first conclusion is that the availability of government R&D support was important in bringing impulse technology to the state it has reached today.
The case study generates convincing evidence for this:

- DOE R&D support facilitated the anchoring of early impulse technology R&D activities at IPC; without DOE's support it would have been more difficult for IPC to start impulse technology R&D.
- Without the DOE's support of IPC/IPST, research would have progressed far more slowly. It is also highly likely that the impulse project would have been stopped at an earlier stage. The continuous stream of support meant that the research activities were not fragmented [Orloff, 2000].
- After commercialisation failed in 1989, DOE continued to support IPST. This allowed the continuation of research into finding a solution for the delamination problem in heavy-weight grades (1988-1992). This provided a necessary background for Beloit to renew its co-operation pick up working with IPST and to reinforce working again on these grades in 1992/93 [Fleischman, 1998; Orloff, 2000; Crouse, 1998].
- DOE supported Beloit by supplying an impulse press for the new pilot paper machine. Without DOE's support the impulse press might never have been installed. It would have been very difficult at that time to convince management to invest another million US$ in an impulse press. IPST's knowledge about cermet coated rolls was critical in convincing Beloit's R&D management that such rolls were also suitable for use in regular (low temperature) pilot machine testing. Without these rolls, it would have been almost impossible to get machine time for impulse technology trials at the pilot paper machine [Crouse, 1998; Orloff, 2000].
- In the absence of government support, Paprican would have had to scale down its efforts and limited its activities to laboratory scale equipment. This would have produced less valuable results [Pikulik, 1998].
- Paprican's activities were closely related to Beloit's private R&D activities. It was in Beloit's interest to be involved closely with Paprican for two reasons; first of all Beloit did not have a pilot paper machine with two press nips (required for light-weight grades); secondly, Beloit's Rockton lab did not have the budget to install an extra press nip in Beloit's existing pilot paper machine [Crouse, 2000; Orloff, 2000].
- The research activities at the US and Canadian national pulp and paper research institutes served as an important support role for Crouse who was the main champion of impulse technology at Beloit [Orloff, 1997; Sobczynski, 1998]. Particularly after the delamination issue had been identified as a stumbling block,

the development of impulse technology did not have a high priority at Beloit [Orloff, 2000; Busker, 2000]. The co-operative efforts with IPST and Paprican and the results achieved helped Crouse to convince others (within Beloit) to continue research activities in that area [Orloff, 2000]. There were sceptics within Beloit, but as a result of the co-operation with Paprican and IPST there was always enough interest and funding for work to continue. Paprican and IPST could bring life to the project with some more research-oriented work, while Beloit could pursue the development work [Crouse, 2000].

- Beloit co-operated with Paprican on light-weight grades and with IPST on heavy-weight grades. Attending to research funding and solving the delamination problem were the two key issues during the development of impulse technology. Co-operation with IPST and Paprican was a way of dealing with both issues [Crouse, 2000].
- STFI would not have started the impulse technology R&D programme without NUTEK's R&D support. NUTEK's support also facilitated the acquisition of additional financial resources to finance the rebuilding of the pilot paper machine [Bergström, 2000; Bäckström, 2000; Norman, 2000; MacGregor, 2000; Hollmark, 2000; Wahren, 2000; Fastmark, 2000]. External support for rebuilding the pilot paper machine was decisive for initiating a major R&D programme regarding impulse technology.
- We doubt whether Valmet would have re-started impulse technology R&D activities without STFI. However, there is no hard proof for this [Talja, 2000].

In concluding that the availability of government R&D support has been important, we must add two important comments.

First of all, the availability of this support certainly influenced the rate of development though it is not yet certain whether impulse technology will lead to improved energy efficiency in paper production. Clearly, this was governments' ultimate stake.

Secondly, the continued effect of R&D support was dependent on the existing relationships and co-operation between the actors in the micro-networks. Actors' resources, equipment and capacities were complementary. People knew each other very well. Without these close interactions, the effect of government R&D support would have been far less effective.

Our second conclusion regarding the effect of government R&D support is that in the impulse technology case the strategy and decisions of the national pulp and paper research institutes were instrumental in the acquisition and utilisation of government R&D support. The national pulp and paper research institutes strongly influenced the decisions that were made regarding the development of impulse technology.

There is evidence that governments played a rather dependent role:

- IPC/IPST continued to stress the advantages of impulse technology and continued to forecast that impulse technology would be commercialised within a few years. The institute was careful to remain secretive about things they did not want to talk about (for instance development of the cermet rolls and the post-nip developments). DOE continued its support for 14 years; it wanted impulse technology to become a success[22] [Crouse, 1998; Pikulik, 1998; Wahren, 2000; Orloff, 2000].

- In Canada, one of the conditions of government R&D support to Paprican was that if the research project was successful, the technology would be implemented on a commercial newsprint machine in Canada. The Canadian government could not force Paprican or Beloit or any of the Canadian newsprint manufacturers to comply with this condition.
- NUTEK showed patience; the idea for impulse technology R&D in Sweden was launched in 1988; a proposal was not submitted until 1996. NUTEK's interest in impulse technology, STFI's wish to rebuild the pilot paper machine and reinforce its position as a leading pulp and paper research institute, additional external financial support needed for rebuilding the pilot paper machine and Valmet's membership of STFI all happened to coincide [Norman, 2000; MacGregor, 2000; Orloff, 1997; Bergström, 2000; Wahren, 2000; Hollmark, 2000].
- The intended co-operation within the IEA was doomed to failure because of the ties between national pulp and paper research institutes and member firms and suppliers. The R&D being done was beyond the pre-competitive level. Whereas international co-operation is often suggested as a way of improving the effectiveness of national energy R&D and demonstration programmes, the actual success of co-operation is highly dependent on the stakes of the actors in the technology network.

We are not suggesting that government's dependency on research institutes is a problem. Such research institutes are generally better informed than government about the potential of a technology and better aware of the needs of their member firms. But undesirable situations may arise, because the research institutes depend on government's R&D support for continuing their research effort. There is a danger that the R&D activities drive the government R&D support instead of the other way around[23]. The paper technology case clearly illustrates that national pulp and paper research institutes interests have more reasons than government for introducing a high-tech energy-efficient technology:

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[22] Very recently, Orloff (2000) wondered whether IPST's R&D activities regarding impulse technology should have continued for so long. The major lesson that IPST learned from the impulse technology project is that a thorough analysis of the economic consequences of the technology on a full-scale commercial paper machine should be made during an earlier phase of an R&D project [Orloff, 2000].

[23] Some of the experts who commented on the draft version of the article had fundamental critics on government R&D support in developing impulse technology. If the technology cannot prove its commercial viability itself, the legitimacy of government support can be questioned. People should develop innovative technology for profit, not in order to get funding for something that is not viable. This comment clearly summarises the main difficulty in granting R&D support. Sometimes, it can be legitimate to support an innovative idea that is not taken up directly by industry. But there is a risk involved in supporting so-called *second rate projects*, which will never be commercialised because profits turn out to be too low.

- Impulse technology was generally presented to government as an energy saver. The experts all agree that energy efficiency alone would never justify R&D expenditure on impulse technology and that paper manufacturers would never invest in such a technology (even if proven successful) solely on the grounds of energy efficiency. We are not implying that researchers have been misleading governments when calculating potential energy-efficiency improvements, but we know that researchers are inclined to stress the parameters of the innovative technology that appeal to the actors addressed. When speaking to government, they stress energy savings; when speaking to paper or board manufacturers they stress paper properties or increased dryness [Orloff, 1997; Sobczynski, 1998; Pikulik, 1998; Wahren, 1998; Fastmark, 2000; MacGregor, 2000; Backström, 2000].
- Clearly, the value of upgrading pilot paper machines goes well beyond one specific R&D effort only. Institutes realise that pilot paper machines are an important way in which they can supply services to member companies and thus generate income. Renewal of pilot paper machines is of strategic importance [Pikulik, 1998; Orloff, 2000; Fastmark, 2000; Hollmark, 2000].

Government showed itself rather patient and persistent in stimulating impulse technology R&D. Some argue that government was too patient and that government should have been more circumspect in evaluating the potential of the technology. Others argue that further R&D is still needed. However, the case study illustrates the risk that government can run. Government should be rather careful about long-term R&D support to specific technologies (which is in itself required in specific cases). If support is continued for a long time, government has to be sufficiently critical in evaluating the potential of the technology; some technologies may turn out to be neither economically feasible nor energy-efficient.

## 4.6. Discussion

We collected the majority, more than 90%, of the articles and reports written on impulse technology by consulting magazines, journals and conference proceedings. IPST’s library (Atlanta, US) was visited. Written information had some limitations. First of all, the majority of the articles came from IPST; hardly any from Paprican; none from STFI or Valmet. Secondly, they generally cover ‘yesterday’s state-of-the-art’ and do not give any competitive information; R&D results using pilot paper machines are all secret and recent R&D results were kept secret until patents were filed. A patent search was carried out to check the completeness of the technology network. Sometimes the patents mention actors who are not mentioned in articles, such as machine supplier Voith and paper manufacturer SCA. It is difficult to assess the technological relevance of patents in view of the large number of patents issued in connection with impulse technology.

Besides consulting the written sources of information, we approached all the major actors and questioned experts who were involved in impulse technology R&D. Firms' and research institutes' stakes regarding impulse technology R&D were and are still high. This not only limits the data available in written form, but it also reduces the possibilities for gathering data via interviews with experts. Experts are not always willing to give complete and frank responses. We were even warned that *'The post-mortem is usually carried out when the projects are completed (successfully or otherwise) and the people are free to discuss the subject" [Pikulik, 1998]*. To circumvent this problem, this chapter was written in two stages. A preliminary version of this chapter was written early in 1998 (see [Luiten and Blok, 1998]). In the second half of 2000, an update of the technology network was made by consulting experts once more. Over these two years, the technology network had changed considerably. We were able to collect more accurate data and reconfirm insights that had been very speculative in 1998. This resulted in a robust analysis of the network and a robust evaluation of the effect of government R&D support.

## 4.7. Conclusion

Impulse technology is considered to be an emerging innovative energy-efficient technology. The aim of this chapter was to evaluate the effect of government R&D support on the development of a specific energy-efficient technology.

More than 25 years of R&D and 15 years of government R&D support have not yet resulted in an economically viable technology. Impulse technology has still not been introduced on a commercial scale. After 10 years Douglas Wahren anchored R&D activities at the US national pulp and paper research institute. From 1980 onwards, a North American micro-network emerged. The US paper machine supplier Beloit became interested and started R&D. Government support made it possible to continue R&D at the US national pulp and paper research institute and to start R&D at the Canadian national pulp and paper research institute. After the first laboratory results were presented during the late 1980s and the shoe press became established technology, R&D activities also took off in Europe. The Swedish national pulp and paper research institute is currently the pivot of a micro-network in which the paper machine supplier Valmet also plays a role.

Our first conclusion is that the availability of government R&D support was important in bringing impulse technology to the state it has reached today. The continued effect of government R&D support was dependent on the relationships between the actors in micro-networks. Actors' resources, equipment and capacities were complementary. Government R&D support cannot be evaluated in terms of energy saved, because the claimed energy-efficiency improvement is still being debated.

Our second conclusion is that the strategy and decisions of national pulp and paper research institutes were decisive in the acquisition and utilisation of government

R&D support. Government was dependent on the research institutes, which led the development of impulse technology. The research institutes in their turn depended on government R&D support for continuing R&D activities. Government's dependency on sector research institutes is not necessarily a problem. These actors are generally better at assessing the potential of innovative technologies and the needs of paper manufacturers. However, undesirable situations may arise if government supports a specific technology for too long a period without checking critically on progress and potential performance characteristics. There is a danger that the R&D activities drive the government R&D support instead of the other way around.

So far, government R&D support has not resulted in a technology that generates a cost advantage and that makes paper manufacturers willing to run the risk of being the first in the field. In fact its energy-efficiency potential is still under debate, the original dewatering mechanism is still not proven, and improvements in paper properties – which are currently believed to be the key to proving the technology's feasibility – are not convincing.

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# Chapter 5

# Strip casting technology


**Abstract**

*Strip casting technology is the most recent innovative steel casting technology that integrates casting and rolling; thus, re-heating the steel is avoided. In this case study, we evaluate the effect of government R&D support on the development of strip casting technology.*

*The original roots of strip casting technology go back to the 19th century. Bessemer, one of the classical inventors of the steel industry, applied for a patent in 1857. After renewed interest in strip casting technology arose between 1980 and 1985, a robust and large technology network emerged. The eleven micro-networks were remarkably homogeneous, a large steel-maker and a machine supplier or engineer. The steel manufacturers took the lead. Six of the eleven micro-networks are still active. Three of them operate strip casting technology on an industrial scale. They needed about fifteen years to achieve this state.*

*The major argument for developing strip casting technology has been the need to reduce the capital intensity of hot rolling. This is especially attractive for small-capacity facilities such as mini-mills and stainless steel facilities. Bessemer was already aware of the huge advantages of direct casting. The introduction of conventional continuous casting (1952), maturing of this conventional technology, the steel crises in the seventies, and the rise of stainless steel and mini-mills had to occur before strip casting technology became the centre of casting R&D activities. Between 1975 and 1985, technologists started looking for more compact casting technologies.*

*Various national governments and the European Coal and Steel Community (ECSC) contributed 5 to 10% of the total expenditure. In three micro-networks, R&D support was more than 40%. These micro-networks stopped R&D activities or deliberately continued on a pilot scale. The three micro-networks that are ahead in developing strip casting technology did not obtain any external R&D support.*

*The major conclusion of this chapter is that the effect of government R&D support on the development of strip casting technology has been minimal. The development proved to have a strong momentum of its own. Strip casting affects the core of steel business; its development was loosely influenced by energy-efficiency improvements or by government R&D support.*

## 5.1. Introduction

Improving the energy efficiency of manufacturing industries is seen as one of the important options for reducing greenhouse gas emissions [IPCC, 1996; UN, 1997]. As a major consumer of energy, the iron and steel industry is always mentioned as a sector where energy efficiency needs to be encouraged. Many steel technologies have been investigated with regard to their techno-economic potential for bringing about energy-efficiency improvement [De Beer et al., 1994; WEC, 1995; IWG, 1997]. There is an increasing interest in the long-term potential of innovative energy-efficient technologies. De Beer (1998) has performed work in this area. He identified several innovative energy-efficient technologies for the iron and steel industry. Long-term savings of 35 to 60% should be achievable [De Beer, 1998]. Financial R&D support for the development of such innovative energy-efficient technologies is often suggested as an attractive strategy for government to reduce $CO_2$ emissions (see e.g. [Blok et al., 1996; De Beer, 1998]). However, very little is known about the effect of R&D support on the development of industrial energy-efficient technologies.

The aim of this chapter is to evaluate the effect of R&D support on the development of an energy-efficient technology. For this purpose, we make a detailed investigation of the networks within which strip casting technology, the most recent innovative casting technology for the steel industry, is developed. Strip casting technology is an interesting case study because both energy-analysts and policy makers consider strip casting technology as one of the major innovative energy-efficient technologies for the iron and steel industry.

In Section 5.2, we briefly introduce the steel industry, the steel production process and strip casting technology. Subsequently, the historical development of strip casting technology is mapped. Section 5.3 sketches the early days of the technology's development up till 1985. In Section 5.4, we describe the more recent R&D history of strip casting technology. In mapping this history we present elements, which are of interest to our analysis of the case study. This analysis is worked out in more detail in Section 5.5. A short discussion of the validity of the analysis is included in Section 5.6. Section 5.7 zooms in on the role of government R&D support. The chapter closes with conclusions about the effect of R&D support in stimulating the development of strip casting technology.

## 5.2. The sector, the production process and strip casting technology

### Iron and steel industry

The production of iron and steel increased substantially after the Second World War. In 1945 worldwide steel production was about 100 millions tons; in 1997 more than

790 millions tons crude steel were produced [IISI, 1998b]. Large integrated steel mills that produced up to 5 million tons steel/year met the huge demand for steel.
From 1970 onwards, prospects deteriorated. World steel prices were forced downwards. Over-capacity, the oil crises during the seventies, the privatisation of former national steel companies, and the growing competition from other materials, forced the steel market to change from a supplier's market to one that was dominated more and more by demand [Holschuh, 1995; Berg, 1996; Vrieling, 1998]. Restructuring was needed and the key-words became efficiency, just-in-time-management, and competitiveness. Quality and flexibility became more important [Birat, 1992; Hamels, 1995; Berg, 1996; IISI, 1998a; Abbel, 1999].
The changed market situation affected R&D within the steel industry. On the one hand process R&D continued; more compact technologies with a lower capital requirement were required. On the other hand product R&D became more important. Co-operative developments with customers (and suppliers) were undertaken [Berg, 1996; Holschuh, 1995; Hamels, 1995; Abbel, 1999; Birat, 1999b].
Steel firms spend about 2.5 billion US dollars annually on R&D [OECD, 1997]. On average, this represents roughly 1% of sales. Integrated steel-makers in industrialised countries often spend more than 1% of their sales on R&D. Small firms spend less. Firm's operating mini-mills undertake almost no R&D[1] [Holschuh, 1995].

## Making steel

There is a wide variety of grades of steel. For the purpose of this chapter, we make a distinction between carbon steel and stainless steel. Carbon steel is steel that relies on the carbon content for its structure and properties. Most of the steel produced is carbon steel. Stainless steel[2], one of the specialty steels, contains more than 10.5% chromium and sometimes other elements. Stainless steel resists corrosion and maintains its strength at high temperatures. Worldwide stainless steel production is about 2% of the world wide crude steel production, which was 776 million tons in 1998 [IISI, 1998b].
The production process for all these grades is to a large extent the same. Differences occur in the last two stages of the steel production process. In total there are four stages:

1. Production of iron
2. Crude steel production
3. Casting into semi-finished products (blooms, billets and slabs)

[1] Mini-mills are small-scale steel mills that melt scrap, using electric arc furnaces, to produce commodity products. Mini-mills differ from integrated steel mills with regard to their minimum annual output, labour relations, product markets, and management style [AISI, 2000]. In 1997, over 33% of the annual steel production was manufactured in mini-mills [IISI, 1998b].
[2] Stainless steel production has increased rapidly in the last decades of the 20th century: over 16 million tons of finished stainless steel were produced in 1997, compared to 13 million tons in 1988, an increase of more than 23 per cent. The largest stainless steel-producing countries are Japan (nearly 4 million tons), the United States (2 million tons), and Germany, Republic of Korea, Italy and France, each of which produced over 1 million tons of finished stainless steel in 1997 [IISI, 1998b].

4. Rolling and shaping final products – hot rolling, cold rolling and finishing operations

The production process is energy intensive due to the chemical reaction energy required in the production of iron, the need for high temperatures and for several re-heating and cooling steps. Such heating and cooling steps can be avoided by using technologies that combine two or three processes. Such technologies can substantially reduce the energy required to produce one ton of steel [De Beer, 1998; IISI, 1998a].

## Strip casting technology

This chapter focuses on strip casting technology. Strip casting does away with the need for re-heating that is still required nowadays when the cast slabs (stage 3) are further processed to final products (stage 4). Strip casting technology permits the production of hot strips, also referred to as hot rolled coiled steel, directly from the liquid crude steel. Casting and rolling are linked into one continuous operation.

Strip casting technology is the most recent innovative casting technology and (thus far) the last technology in realising direct casting. We use the generic term direct casting to denote casting in sizes that are as close as possible to final products. In this chapter, we show that direct casting has been realised in a step-wise fashion: the thickness of the sheet or strip cast has been reduced by three innovative technologies, conventional continuous casting, thin slab casting and strip casting technology (see Figure 1).

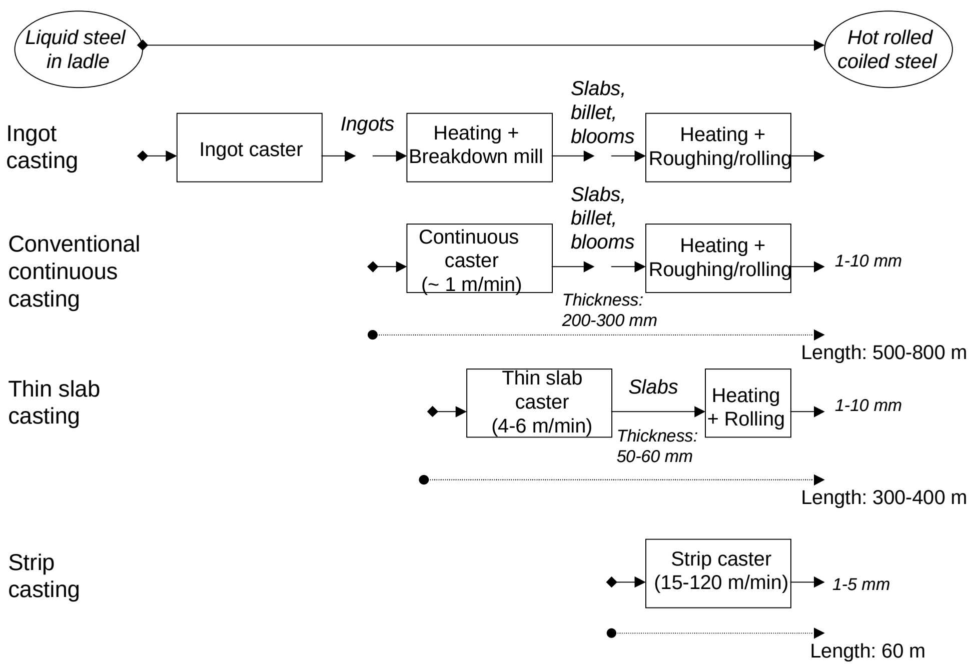


*Figure 1: Technological development in the casting and rolling stages of the steel production process: ingot casting, conventional continuous casting, thin slab casting and strip casting technology.*

Before 1960 all liquid crude steel was cast in ingots. After cooling the ingots were reheated and processed into semi-finished products such as slabs, blooms and billets. Continuous casting technology allowed liquid steel to solidify directly into these semi-finished products. A continuous process replaced the traditional batch process of pouring ingots first. Continuous casting avoided large capital expenditure on soaking pits and breakdown mills.
The introduction of thin slab casting (1989) let the liquid steel be cast in thinner slabs (see Figure 1). Blooms and billets cannot be produced with a thin slab caster. Thin slab casting technology integrates casting and the finishing operations in the hot rolling section of a steel plant. The cast slabs are charged directly into a reheater and subsequently fed into the hot rolling mill. The reheating capacity for hot rolling the slabs is thus reduced.
Strip casting technology makes it possible to cast the liquid steel in sizes that are even closer to final products. Note that this limits the range of final products that can be produced [Schors, 1996].

In a strip caster, a ladle is filled with liquid crude steel. The crude steel flows into the tundish, in which the steel is buffered and the temperature is controlled. The tundish feeds the liquid steel through a nozzle to the mould. The mould, which has a capacity of about one hundred litres, is composed of one or two casting rolls. The rolls are water-cooled. To achieve high productivity, high casting speeds are required (see Figure 1).

There are three technical difficulties in developing strip casting technology, namely edge containment, liquid steel feeding to the mould and properties of the rolls.
The first difficulty is related to the edges or the lateral sides of the mould. These should form a perfect seal with the rotating rolls to prevent leakage. Premature solidification at the edges should be avoided. This causes a poor quality at the edges of the strip (leading to yield losses) and inhibit continuous casting.
A second difficulty is that the liquid steel should be fed to the mould in such a way that the level of steel in the mould remains constant. A perfectly even level has to be maintained to prevent surface defects and irregularities in the thickness of the strip.
Thirdly, the rolls that form the mould need specific attention. On the one hand they are extreme heat exchangers (8-15 $MW/m^2$) that should be able to handle enormous temperature differences (200-300 ºC/cm). On the other hand they need to produce crack-free strips that vary in thickness by less than 30 µm.

The major advantage of strip casting technology is that the capital expenditure for producing hot rolled coils will be considerably lower than for a conventional casting and rolling mill: the capital-intensive hot strip mill is no longer needed[3]. Total capital expenditure will be a factor 4 to 10 lower [Birat et al., 1995; Hendricks, 1995; Lindorfer et al., 1993; Schors, 1996]. The capital costs per ton steel are estimated to

[3] Flemming et al. (1988) indicate that in the case of conventional continuous casting about 70% of the capital expenditure is spent on the hot rolling mill.

be about 40% lower than for conventional casting and rolling operations [Hendricks, 1995; Schors, 1996]. Experts indicate that the operating costs per ton steel are subject to a larger uncertainty primarily due to uncertainties in material costs due to requirements to the roll materials and the problems in edge containment [Lindorfer et al., 1993]; Birat et al., 1995].

Energy costs will decrease. Strip casting technology considerably reduces the energy needed to cast one ton of steel[4]. Because energy costs are only a small part of the operating costs *of the casting and rolling* stages (see also [Schors, 1996]), the energy cost saving is modest [Senk, 2000; Cramb, 2000]. We estimate that the energy cost saving is an order of magnitude lower than total cost saving[5].

Strip casting technology leads to considerable strategic advantages for relatively small steel firms, i.e. 0.5 million ton steel / year. Most stainless steel firms are relatively small. Such firms do not have a hot rolling mill at their sites: the capital costs per ton steel are too high to be competitive. The lower capital expenditure of strip casting allow such firms to process the cast steel into final products themselves. Outsourcing is no longer required. Storage facilities are no longer needed. Semi-finished products do not have to be transported to a hot rolling mill. Throughput times and costs for planning and transport are considerably reduced. Strip casting technology also opens up the cold rolled market for mini-mills [Millbank, 1995; Hendricks, 1995; Birat, 1992].

Finally, some people argue that strip casting technology creates opportunities for the development of new products [Senk, 2000; Robson and Thompson, 1995; Millbank, 1995; Anonymous, 1994].

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[4] IISI (1998a) estimates the reference primary energy consumption in the casting and rolling stages (using a conventional continuous caster, a re-heater and a rolling mill) to be 2.3 $GJ_p$/ton steel [IISI, 1998a, pp. 74, 100-102]. De Beer (1998) estimates that the primary energy needed for casting and rolling is 2.4–2.7 $GJ_p$/ton steel. This is roughly 15% of the total primary energy requirement of an integrated mill, i.e. 19 $GJ_p$/ton [De Beer, 1998, p. 150]. IISI (1998a) estimates that thin slab casting technology consumes roughly 1.0 $GJ_p$ / ton and that strip casting technology may consume 100 $MJ_p$ / ton [IISI, 1998a, pp. 196-197]. Thus, applying strip casting technology saves about 900 $MJ_p$ per ton steel *compared to the thin slab casting route* (based on [IISI, 1998a]). About 60 kWh less electricity is needed. No fuel is required for reheating the furnaces, which is about 350 $MJ_p$ / ton [IISI, 1998a]. Applying a strip saves about 2.0-2.5 $GJ_p$ per ton steel *compared to conventional continuous casting* (based on [IISI, 1998a]). Recent performance data from the Krefeld caster indicate that strip casting technology requires about 400 $MJ_p$ per ton steel. At the Krefeld site, the reference energy for conventional casting and rolling is 3.2 $GJ_p$ [Walter et al., 2000].

[5] It is difficult to make a precise calculation of the savings in energy costs as a percentage of total cost savings. First of all, there are differences in the cost structure of carbon steel and stainless steel. Secondly, there are differences in cost structure of steel manufactured in an integrated mill or in a mini-mill. Sources indicate that the total cost savings achieved when a strip caster is introduced at a *stainless* steel site are 2 to 5 times higher than when a strip caster is introduced at a *carbon* site [Bagsarian, 1998]. The costs of producing one ton of *carbon* steel vary between 225-325 US$ / ton (see e.g. [Hamels, 1995; Schors, 1996; Faurre, 1993; Daniels and Moll, 1998]). Variation is explained by differences in the route to produce steel (integrated or mini-mill) and differences among geographic regions [Faurre, 1993; Schors, 1996]. We estimate that casting and rolling in an *integrated mill* cost around 100 US$ per ton steel [Schors, 1996; Lindorfer et al., 1993]. Casting and rolling in a *mini-mill* is estimated to cost 50 to 60 US$ per ton. Around 40% of the costs are capital costs [Schors, 1996; Lindorfer et al., 1993]. Energy costs for casting and rolling in a mini-mill are less than 10% of the operational costs [Schors, 1996].

## 5.3. Historical development of strip casting technology

In this section, the historical development of strip casting technology is mapped up till 1985. We start at the moment when *none* of the known forms of direct casting - conventional continuous casting, thin slab casting, and strip casting technology – had yet been applied commercially. The history is described in three steps: the history up till 1940; the introduction of conventional continuous casting technology (1940-1975); and the renewed R&D interest in casting technologies (from 1975 onwards).

### Development of strip casting technology up till 1940

The idea of using a twin roll caster for casting strips directly from liquid steel without any reheating attracted Sir Henry Bessemer's attention as long ago as 1846 [Bessemer, 1891]. Bessemer was one of the important inventors in the steel industry who made the production of cheap steel possible by the invention of the steel converter [Jewkes et al., 1960]. With respect to strip casting technology, he started from an existing patent describing twin roll casting of tin foil and lead. After doing some experiments, he was so impressed with the importance of his invention, that he immediately applied for a patent in 1857 [Bessemer, 1891]. Because Bessemer's invention of the steel converter was at that time judged as *" … an absolute failure. One need not, therefore, be greatly surprised that the production of continuous sheets direct from fluid iron did not excite a great amount of enthusiasm in the minds of tin plate manufacturers of that day; in fact, the whole scheme was simply pooh-poohed and laid aside, without any serious consideration of its merits" [Bessemer, 1891, p. 27]*. Bessemer noted that there were difficulties in feeding the liquid steel to the mould, with edge containment and properties of the cast strip. Since he felt his idea was before its time and he was being pressed to make his steel converter work, he did not continue with the development of strip casting technology [Cramb, 1989]. A sketch of Bessemer's twin roll caster is shown in Figure 2.

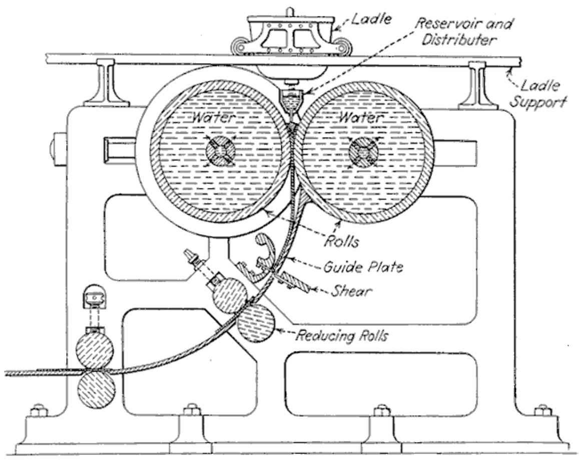


*Figure 2: Bessemer's twin roll strip caster.*

Bessemer was aware of the activities of the American Edwin Norton. Norton had sent him a parcel containing a small sample of a steel sheet that he claimed had been cast in accordance with Bessemer's idea [Bessemer, 1891]. In 1890, Norton conducted experiments on twin roll casting using a pilot machine producing 3-5 mm thick sheets [Cramb, 1989; Norton, 1940]. A fire in Norton's factory and the mechanical difficulties he encountered made Norton decide that further development which required substantial investment was not justified [Norton, 1940].

It was not until the 1920s that any new research was done on Bessemer's idea [Hazelett, 1966]. Only a few projects are described in literature; of these Hazelett's activities were the most conspicuous[6] [Cramb, 1989]. Hazelett picked up the idea and successfully built a number of twin roll casters for the production of lead, aluminium and brass strips [Hazelett, 1966; Cramb, 1989; Wolf, 1992]. Hazelett also produced some cast steel, although problems with properties of the cast strip and with the roll materials forced him to redesign his twin roll caster [Lippert, 1940; Hazelett, 1966; Cramb, 1989]. First he tried to overcome these problems by switching to a single roll caster [Lippert, 1940]. Again he encountered problems, like variability in strip thickness, properties and edge containment. As a result Hazelett abandoned *roll* casting processes in the 1940s. He concluded that a mould consisting of two moving belts was the preferred casting method. Such a caster is nowadays known as the Hazelett caster and is commercially for all kinds of metals but not steel [Hazelett, 1966].

### 1940-1975: Development of continuous casting

By 1940, all R&D activities on casting using a mould with rotating rolls were terminated [Cramb, 1989]. By that time, the casting R&D efforts were focused on the conventional continuous caster as suggested by Siegfried Junghans in 1927[7] [Jewkes et al., 1960; Lippert, 1940; Wolf, 1992]. Junghans used a stationary mould for direct casting, not rotating rolls as in a strip caster. The technology was first applied to a brass plant in 1937. In 1952, Mannesman, a German machinery supplier, installed the first continuous caster for steel. For a number of years continuous casting was confined to small steel plants due to technical limitations. Only from 1970 onwards, continuous casting was started to be used in integrated steel mills casting slabs [Nasbeth and Ray, 1974; Nilles and Etienne, 1991]. With continuous casting it became possible to cast semi-finished products directly. Substantial savings in both capital and energy costs and a considerable increase in product yield were achieved [Wolf, 1992].

### From 1975 onwards: Renewed R&D interest beyond continuous casting

*"Continuous casting (was) a strong paradigm of process innovation in the steel industry from the 1950s to the 1980s" [Birat, 1999b, p. 1389]*. However, from 1975

[6] In the same time as Hazelett's work, a strip casting effort was underway in the USSR [Cramb, 1989].
[7] For an extensive description of the history of conventional continuous casting see [Wolf, 1992].

onwards R&D activities concentrated on casting liquid steel in sizes that are even closer to final products [Wolf, 1992; Birat, 1999b]. Steel-makers started to look for innovative technologies that could extend the advantages of continuous casting. They investigated many different moulds that would allow thinner casting. Not only Hazelett belt casters, but also Bessemer's suggestion of two rotating rolls were picked up again. At least a hundred R&D efforts were started in the period 1975 – 1985 [Kubel, 1988; Tony, 1990; Birat et al., 1995; Cramb, 2000; Birat, 2000].
The Hazelett belt caster was a favourite mould among many steel firms[8] [Senk, 2000; Cramb, 2000]. This caster was already used in R&D during the 1960s [Cramb, 1989]. The technical problems that hampered the R&D activities in the 1960s were not inherent to caster and renewed R&D efforts were initiated. However, again no commercially viable technology emerged because machine suppliers succeeded in developing and commercialising thin slab casting technology [Birat, 1999b]. The German supplier SMS was the first to install a thin slab caster in 1989 at Nucor, an American mini-mill operator. The funnel-shaped mould was new, the rest of the design was basically the same as that of the conventional continuous caster [Cramb, 1989; Birat et al., 1995]. It was only a matter of time before other suppliers commercialised their thin slab casters[9]. Steel firms stopped their R&D activities on Hazelett casters; the Hazelett casters promised casting in the same thickness range [Birat et al., 1995; Thompson, 2000; Senk, 2000].
The success of thin slab casting did not stop steel-makers from searching for technologies realising even thinner casting. The R&D efforts that focused on Bessemer's strip casting technology were continued [Anonymous, 1993].

## 5.4. Recent development of strip casting technology

In this section, we sketch the more recent development of strip casting technology by focusing in detail on the eleven micro-networks that can be distinguished since 1985. The majority the strip casting R&D efforts that started between 1980 and 1985 were terminated.
We use the terms hot model, pilot caster and industrial scale caster to denote the different scales of the equipment used. A *hot model* denotes a small pilot plant. Liquid supply is only a few hundred kilograms; strip width is typically 10–25 cm. The term *pilot caster* is used to denote a caster with restricted liquid supply, but a

[8] Krupp Stahl (Germany), Mannesman (Germany) , British Steel (UK), Bethlehem Steel and US Steel (US), Nucor (US), Nippon Steel Corporation and Mitsubishi, Kawasaki Steel, Kobe Steel, Sumitomo Metals, and Hitachi Zosen (all Japan) (see e.g. [Kubel, 1988; Evans et al., 1988; Cramb, 1989; Tony, 1990; Birat and Steffen, 1991; Birat et al., 1995]).
[9] Mannesman (Germany), Voest Alpine Industrieanlagebau (Austria), Danieli (Italy) and Sumitomo Heavy Industries (Japan) [Steffen and Tacke, 1999]. The introduction of thin slab casting facilitated the increase of steel manufacturing in mini-mills, first in the US and later also in other countries [Birat et al., 1995].

larger strip width, i.e. 80-160 cm. An *industrial scale caster* has both a large liquid supply, larger than 60 ton, and a larger strip width 80-160 cm.

### Allegheny Ludlum (US) and Voest Alpine Industrieanlagebau (Austria)

During the early 1980s, the US steel-maker Allegheny Ludlum started to develop a single roll caster for speciality steels. The major arguments were to do away with expensive hot strip mills and to produce new grades of steel[10] [McManus and Berry, 1993; Hess, 1991; McAloon, 1991; Isenberg-O'Loughlin, 1988]. Allegheny preferred a single roll caster, because of earlier R&D experience with rapid solidification [Birat et al., 1995]. In 1984, Allegheny Ludlum surprised the steel industry by claiming that they had been successful in strip casting. Allegheny's claim placed strip casting technology on the agenda of many boards of directors of steel-making firms [Birat et al., 1995; Thompson, 2000; Cramb, 2000; Birat, 2000].

Voest Alpine Industrieanlagebau, an Austrian machine supplier, had been involved in the development of thin both slab casting and strip casting technology since the mid-1980s. The argument for developing both innovative technologies was the potential capital savings [IISI, 1993]. Thin slab casting was not seen as the ultimate direct casting technology and therefore Voest also performed single and twin roll casting experiments [Hohenbichler, 2000]. Twin roll casting was found to be more difficult than single roll casting. R&D activities focused on carbon steel [Birat and Steffen, 1991; Kubel, 1988].

For continuing R&D activities, Allegheny needed a machine supplier that could build a pilot caster. Voest was approached. Allegheny and Voest signed an agreement in 1988. Voest's experience with casting carbon steel complemented Allegheny's activities in the field of stainless steel. Aim of the joint effort was to bring strip casting technology towards commercialisation. In 1988, the firms expected that the process could be commercialised in the mid-1990s for stainless steel [Ritt, 1998; McAloon, 1991; Lindorfer et al., 1993; Hess, 1993]. In 1990, a decision was made to build a pilot caster at Allegheny's Lockport site. The pilot caster was called Coilcast [McAloon, 1991]. The firms claimed that capital costs and operating costs could be reduced by 75% compared to the costs of conventional casting and rolling [Hess, 1991; Lindorfer et al., 1993].

Coilcast had been tested for two years before it was suddenly shut down in 1994 [Schriefer, 1997]. Allegheny dropped all its R&D activities without any public statement. There was no longer confidence that steel could be cast successfully. The development had already taken more than 13 years [Williams, 1999; Schriefer, 1997; Birat, 2000; Cramb, 2000].

[10] Allegheny Ludlum was driven by competition with Allied Signal. Allied Signal has a commercial twin roll caster at its disposal (see [McManus, 1997]). Allied Signal aimed at producing a product that could compete with a market that was served by Allegheny [Cramb, 2000].

## Armco (US)

In 1983, the US Department of Energy (DOE) decided to support feasibility studies on strip casting technology. Allegheny Ludlum brought the technology to the attention of DOE. DOE's was interested, because of the substantial energy savings expected. Allegheny Ludlum was not interested in government support. Their R&D activities were beyond the stage of a feasibility study [Williams, 1999; Cramb, 1989]. Four teams did acquire R&D support for performing such a feasibility study. One team consisted of Westinghouse, a producer of electronic consumer products, and the US steel-maker US Steel. Westinghouse studied a single roll caster. In 1984, Westinghouse was selected for a second phase study. DOE preferred this project because it was targeted at carbon steels that promised the largest energy savings potential. US Steel withdrew their contribution when they decided to invest in the development of thin slab casting (also supported by DOE)[11] [Kubel, 1988; Hess, 1991; Cramb, 1989]. Westinghouse approached Armco. Armco had attempted casting R&D using a Hazelett caster and was interested to pursue the development of a single roll caster [Cramb, 1989]. The contract was extended to a third (1988) and a fourth contract (1991). Armco became the prime contractor [Isenberg-O'Loughlin, 1988]. DOE contributed around 12 million US$, 70% of the total expenditure. Westinghouse and Armco retained the right to patent their findings [Willimas, 1999; Isenberg-O'Loughlin, 1994].

In late 1993, when Armco was half-way through the fourth contract, it suddenly terminated its participation. The triggering event was that Armco's carbon steel-making division was sold. Armco became a firm producing specialty steels [Isenberg-O'Loughlin, 1994; Ritt, 1998; Sheridan, 1997]. Furthermore, R&D results from other micro-networks made Armco believe that a *twin* roll caster was the preferred solution [Cramb, 2000; Williams, 1999; Ritt, 1998].

## Other R&D activities in the US

Not only Allegheny and Armco, but also other US steel firms explored strip casting technology during the early eighties. Bethlehem Steel, for instance, started twin roll casting R&D in 1981. Around 1986, they formed a partnership with Armco, as well as with Weirton, and Inland Steel. Argonne National Laboratory financed by DOE was involved in this effort to deal with the edge containment problem [Cramb, 1989; Hess, 1991; Isenberg-O'Loughlin, 1994; Isenberg-O'Loughlin, 1988]. The effort ended because they could not find a solution for this difficulty and could not cast reproducible grades of steel [Birat et al., 1995; Kuster, 1996]. By the year 1994, all strip casting R&D activities in the US were terminated.

In April 1998, US strip casting R&D was 'restarted'. Carnegie Mellon University (CMU) and the American Iron and Steel Institute (AISI) has started a 3-year multi-

[11] In 1984, DOE awarded US Steel and Bethlehem Steel a 30 million US$ grant to develop a thin slab caster using a Hazelett caster [Kubel, 1988; Cramb, 1989; Hess, 1991].

partner R&D project within the Industries of the Future Initiative of the US Department of Energy. Research institutes, steel-manufacturers and machine suppliers are involved[12]. Aim of the project is to analyse the properties of strip cast steel in order to assess the possibilities of producing new grades of steel and other advantages of strip casting technology to the US steel industry [Cramb, 1998].

### Usinor Sacilor (France) and Thyssen (Germany)

The French integrated steel-maker Usinor Sacilor started experimenting with strip casting in the mid-80s [Grosjean et al., 1993]. Both single and twin roll casters were investigated. After some numerical simulations and design concepts, Usinor decided to build a hot model at the research institute IRSID in 1986[13]. A twin roll caster was found to be more promising [Birat and Steffen, 1991]. Between 1986 and 1990, IRSID received some R&D support, 10 to 15%, via the research programme of the European Community on Steel and Coal (ECSC) [Birat, 2000].

The German integrated steel-maker Thyssen started research on strip casting technology around the same time as Usinor. Thyssen worked together with the Institut für Bildsame Formgebung (RWTH) in Aachen. A hot model was available in 1988 [Grosjean et al., 1993]. Experiments were done on twin and single roll casters. Thyssen also considered twin roll casting more promising [Simon et al., 1997]. Thyssen received some support by the German Bundesländer. Several projects were supported by the ECSC though they did not specifically focus on strip casting, but were also valuable for thin slab casting technology [Senk, 2000].

Thyssen and Usinor had co-operated in R&D before and in 1989 it was decided to merge their R&D activities in strip casting technology[14] [Grosjean et al., 1993; Hendricks, 1995]. The argument was to share the investment costs of the pilot caster [Birat, 1999a; Senk, 2000]. The joint venture is known as Myosotis. The pilot caster was located at Isbergues, a stainless steel site of Usinor. The plant was built by the French machine-builder Clecim. After a planning and construction period of 20 months, the first experiments started in June 1991 at a ladle capacity of 10 tons. The ladle capacity was gradually increased. In October 1995, a complete ladle of 92 tons was cast. The main interest was in the casting of stainless steel, but carbon and silicon steel casting experiments were also performed.

During 1997 several articles on the results of the Myosotis project were published (see e.g. [Legrand et al., 1997a; Legrand et al., 1997b; Simon et al., 1997]). By then, the researchers were convinced that it was no longer the question whether the

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[12] R&D institutes: CMU (US), Max Planck Institute (Germany). Associate organisation: AISI. Steel-makers: AK Steel Corporation (US), British Steel R&D lab (UK), Dofasco (Canada), LTV Steel Company (US), National Steel Corporation (US), US Steel / US X (US). Suppliers: SMS Steel (US), Kvaerner Metals (US) [Cramb, 1998].

[13] IRSID used to be the R&D institute of the French national steel firms. It became Usinor's corporate R&D lab in 1988 [Birat, 1999a].

[14] Thyssen and Usinor also co-operated in the area of thin slab casting technology. Together with SMS, a German machine supplier, they developed the Casting-Pressing-Rolling process [Birat et al., 1995; IISI, 1998a].

technology would have an industrial future, but only when it would become operational [Legrand et al., 1997b].

### Centro Sviluppo Materiali and Acciai Speciali Terni (Italy)

The steel research institute Centro Sviluppo Materiali[15] (CSM) and the Italian steel-maker Acciai Speciali Terni (AST) started strip casting R&D in 1985 [IISI, 1993; CSM, 2000]. First, the feasibility of the process was studied. In a second phase (1987-1988) a hot model was designed and constructed in Rome. There was then a third phase in which a pilot caster was designed and built at AST's steelworks in Terni in 1989 [Shin, 1990; Birat and Steffen, 1991; Macci and Mollo, 1995]. The Italian engineering firm INNSE was involved in constructing the pilot caster. In 1993, industrial operation was foreseen by the end of 1996 [IISI, 1993]. Some results of the pilot caster were reported in 1995. However, surface quality did not meet the requirements of its conventional equivalent [Macci and Mollo, 1995]. Until 1995, AST and INNSE paid for the research done by CSM. The research at CSM was partly supported by the ECSC, i.e. 20 to 30% of the budget [CSM, 2000].

In 1995, the Austrian machine-builder Voest Alpine joined the CSM/AST micro-network as an equal partner. Voest became involved in upgrading the Terni facility to the size of an industrial scale caster. Voest's R&D experience in the former partnership with Allegheny made them an attractive partner for CSM/AST [CSM, 2000; Hohenbichler, 2000]. During the summer of 1997, the Terni plant was supplied with two new 30 ton ladles [Bagsarian, 1998]. Expenditure between 1995 and 1997 was considerably higher than in the period 1985 to 1995. In this phase, no further application was made for ECSC support [CSM, 2000]. One did obtain financial support by the European Commission (EC) for building a new industrial scale caster at Terni in September 1996. Improving energy efficiency was the main rationale behind the EC's decision to support the demonstration facility[16].

### Krupp Stahl (Germany) and Nippon Metal Industry (Japan)

The Japanese Nippon Metal Industry had been developing strip casting since 1980. Joint R&D activities between the German steel-making firm Krupp Stahl and Nippon Metal Industry started in 1986. The activities focused on a mould using rolls of unequal diameter [Shin, 1990]. In 1990, two pilot casters were operational, one in Germany and one in Japan. Krupp acquired support by the ECSC and the German Bundesländer [Pfeifer et al., 1993; Birat and Steffen, 1991]. After the merger of Krupp with Hoesch in 1992, changes in the organisation of Krupp and the idea that considerable extra R&D was still needed made Krupp decide to stop [Millbank,

[15] Up till 1994, CSM was the national research institute of the Italian steel industry. In 2000, CSM is a privatised research institute in the field of steel and metallurgy. CSM has different shareholders. The stainless steel firm Acciai Speciali Terni (AST) owns 15%.

[16] THERMIE programme / 4$^{th}$ FWP / IN/00124/96. Title: Abatement of energy consumption in the steel hot strip production through a near net shape casting process. Prime contractor: AST, Terni. Duration: September 1996-November 1999 [Cordis, 2000].

1995; Cramb, 2000; Senk, 2000]. Nippon Metal stopped its strip casting activities as well [Birat et al., 1995].

### Eurostrip: Merged micro-networks

In 1994 the Italian steel firm AST was taken over by the German steel-maker Krupp. CSM and AST continued their strip casting R&D activities. In 1997, Thyssen merged with Krupp. The newly formed Thyssen Krupp Steel had a stake in the Italian micro-network and the French – German Myosotis project. The activities in these two micro-networks were formerly merged in 1999. Experienced researchers and engineers from AST and CSM, Voest, Thyssen Krupp Steel, and Usinor and IRSID were brought together.

Due to the merger, stainless steel producer Krupp Thyssen Nirosta (KTN) became a sister company of the Italian AST. Whereas, KTN had some strip casting R&D experience, they carried out two ECSC projects between 1991 and 1995, they were rather sceptical about the possibilities of strip casting technology. After KTN visited the Terni caster, interest in the Italian strip caster grew. In December 1998, it was decided to build an industrial caster at KTN's Krefeld site instead of at AST's Terni site. The Krefeld site was particularly advantageous because it did not have a hot rolling mill [Walter et al., 2000]. The European Commission permitted the financial support to be used to build an industrial scale caster in Krefeld instead of in Terni [CSM, 2000; Senk, 2000]. In September 1999, Thyssen Krupp Steel, Usinor and Voest formed a firm called Eurostrip. Voest is the exclusive supplier of Eurostrip strip casting technology. In December 1999, the first stainless steel was cast. The Krefeld caster's annual capacity will be enlarged from 100,000 tons/year to around 400,000 tons/year within 2 or 3 years [Anonymous, 1999; Thyssen Krupp Steel, 1999]. The Myosotis project was formerly stopped in 1998. R&D activities in Terni are continued for developing carbon steel strip catsing. The Eurostrip partners are involved in ECSC supported co-operative multi-partner projects on carbon steel. Europstrip partners expect that the carbon steel market for the exploitation of strip casting will develop rapidly from 2001 [Hohenbichler et al., 2000].

### Nippon Steel Corporation and Mitsubishi Heavy Industries (Japan)

The consortium of Nippon Steel Corporation (not to be confused with Nippon Metal mentioned earlier) and the machine-builder Mitsubishi Heavy Industries was formed in 1985 [IISI, 1993; Millbank, 1995]. They concentrated on stainless steel. Mitsubishi and Nippon Steel were financially equal partners [Tacke, 1999; Birat, 1999a; Cramb, 2000]. Their first hot model was built in 1986. In 1988, they extended this model to a pilot caster at Hikari. In 1993, some promising results were reported. Nippon Steel and MHI announced that the focus would shift towards studying the economic feasibility of the technology and the building of an industrial scale caster [IISI, 1993]. In September 1997 it was reported that the industrial scale caster had reached the design capacity of 400,000 ton/year. In October 1998, Nippon Steel was selling strip cast stainless steel. Nippon Steel reported that the greatest advantage of the strip caster was that the production time was reduced to less than an hour. Casting and finishing operations were linked by the strip caster and thus transport was no longer required [Furukawa, 1997; Furukawa, 1998].

### Broken Hill Proprietary Company (Australia) and Ishikawajima-Harima Heavy Industries (Japan)

The Australian Broken Hill Proprietary Company (BHP) and the Japanese machine-builder Ishikawajima-Harima Heavy Industries (IHI) had an established business relationship, when they started co-operative R&D activities relating to strip casting in 1985. In 1990, a pilot caster at Unanderra was realised [Furukawa, 1994]. At first, BHP investigated casting stainless steel, like most of the other micro-networks. Focus shifted to carbon steel when the project moved on towards the realisation of an industrial scale caster [Opalka, 1998]. In December 1994, the industrial scale caster, called Project M, was constructed at Port Kembla. The main purposes of the plant were to proof the durability of the rolls, the consistency of product quality and improve the accuracy of process control [Furukawa, 1994]. BHP achieved its breakthrough in December 1997 with the production of its first saleable carbon steel.
Up till November 1998, BHP and IHI were secretive about Project M [Opalka, 1998; Birat et al., 1995]. Then, they announced that Project M was very close to commercialisation [Abbel and Moonen, 1998]. They claimed that the advantage of Project M is that the strip caster shortens the production process, both physically and in time, and integrates casting with rolling operations. BHP was determined to exploit this advantage in new mini-mills in the East-Asian region [BHP, 1998; MacLeay, 1998; Millbank, 1995]. Confronted with the Asia crises, however, BHP decided not to build mini-mills. Early in 2000 it was announced that Nucor, the US mini-mill steel firm that was also the first to build a thin slab caster, had signed a letter of intent with BHP and IHI for the establishment of a joint venture for the worldwide licensing of BHP’s strip casting technology. Start-up of the first commercial facility is expected in 2001 [Anonymous, 2000; Nucor, 2000; BHP, 1999].

### Hitachi Zosen and Pacific Metals (Japan)

Hitachi Zosen, a Japanese machine-builder, experimented with twin roll casting between 1981 and 1985 on an irregular basis. More serious activities started in 1985. As a result, Hitachi wanted to build a pilot caster in 1987. The firm started looking for a steel partner. Pacific Metals, a relatively small stainless steel company (and subsidiary of Nippon Steel), joined [Birat et al., 1995]. The pilot caster, called Hachinoe, became operational in 1990 [Freuhan, 1994; Parodi, 1993; Shin et al., 1995]. Around 1994, the US steel-maker Inland Steel became involved [Anonymous, 1994]. Inland had developed an electro-magnetic edge containment system during the 1980s. Inland Steel had obtained some experience with the technology in their partnership with Bethlehem Steel, Armco and Weirton (1986) [Cramb, 1989; Isenberg-O'Loughlin, 1994]. An agreement was signed with Hitachi Zosen to determine the feasibility of the edge dam on Hitachi's pilot caster [Isenberg-O'Loughlin, 1994]. The agreement however did not result in any adaptations to the pilot caster. Hitachi and Pacific's current intentions remain unclear.

### British Steel (UK)

British Steel started research in 1986 at its Teeside Technology Centre. A small hot model was used for casting carbon and stainless steel. In parallel with this investigation, a marketing study identified target markets for the technology [IISI, 1993]. In 1990, the existing hot model was scaled up to a larger one. Davy, a UK engineering firm, built the machine. British Steel experimented with some innovative technologies which were all abandoned [Birat et al., 1995; Kuster, 1996].

British Steel Stainless was interested in the possibilities of strip casting, because they wanted to integrate casting with cold rolling. At that moment hot rolling was out-sourced. When British Steel Stainless merged with Avesta Sheffield, a Swedish stainless steel manufacturer in 1992, a hot rolling facility was provided and there was less need for strip casting technology [Wilkinson, 1998].

British Steel however continued their R&D. Their objective changed: they merely wanted to maintain their expertise. British Steel's wants to be an 'educated customer', so that it can act as an informed buyer once strip casting technology becomes available [Thompson, 1999; Wilkinson, 1998; Millbank, 1995].

Most of the strip casting R&D carried out at British Steel was funded by the ECSC. British Steel was involved in three individual projects. It has also been involved in two ECSC supported multi-partner projects, together with the Eurostrip partners, on strip casting carbon steel [Birat and Steffen, 1991; Millbank, 1995; Thompson, 2000].

### Project Bessemer and the Industrial Materials Institute (Canada)

Between 1986 and 1989 the Canadian steel industry identified strip casting as an interesting technology for co-operative research. In a thorough survey of world-wide casting R&D activities, the enormous potential for capital and operating cost reductions by strip casting technology was highlighted [IISI, 1993]. The Canadian Industrial Materials Institute (IMI) had already started strip casting R&D in 1987 driven by the feeling that there was strong interest among Canadian steel-makers [Hamel, 1999]. And indeed, a consortium of six Canadian steel firms was formed in 1989[17]. The consortium is called "Project Bessemer". The consortium asked IMI to carry out R&D on strip casting carbon steels [IISI, 1993; Birat et al., 1995]. The Canadian steel firms preferred a twin roll caster because of its potential for good strip surface quality. Furthermore, carbon steel was chosen as the main grade, simply because none of the steel firms produced stainless steel. A hot model was installed

[17] Dofasco, Stelco, Ipsco, Ivaco, Ispat-Sidbec and Algoma (80% of the Canadian steel production).

during the summer of 1992 by Hatch et Associés, a Canadian engineering firm [IISI, 1993; Hamel, 1999].

Between 1989 and 1992, the consortium developed a research programme, that was financially supported by the Canadian National Research Council. Goal of the programme was to develop a strip casting process that could produce low cost, high quality carbon steel. In January 1997, an agreement was signed with Hatch et Associés. They got the right to design future strip casting plants [Project Bessemer, 1997; Hamel, 1999]. However, the research programme was stopped in 1998 [Steffen and Tacke, 1999]. There are no signs that any of the firms in the Bessemer Consortium is engaged in taking the next step. This may be due to a number of factors: BHP's progressed in casting carbon steel; three of the Canadian steel-makers invested in thin slab casters; there is no machine-builder involved; and finally substantial financial resources are required. Investments in an industrial caster would require an additional 65 million US$ [Bagsarian, 1998; Hamel, 1999; Millbank, 1995].

The major argument for the steel-makers to start the co-operative R&D programme in the first place was to keep abreast of strip casting technology. The steel-making firms are pleased with the dividends that the programme has paid to date. Each firm has spent a fairly restricted amount of resources and the knowledge coming back to them has been considerable [Isenberg-O'Loughlin, 1994; Millbank, 1995; Hamel, 1999].

### Pohang Iron and Steel Company (South Korea)

The Korean Pohang Iron and Steel Company (POSCO) and the Research Institute of Industrial Science & Technology (RIST) started work on strip casting in 1989[18] [Shin et al., 1995]. POSCO's efforts in strip casting have started relatively late, because it is only since 1987 that POSCO has pursued an active R&D strategy. After a period in which POSCO concentrated on expanding its steel production capacities, POSCO wanted to reinforce its competitiveness by strengthening its R&D activities. One of the long-term projects started was a strip casting project [Kang, 2000]. POSCO's aim is to develop an industrial scale strip caster, that is less capital intensive than conventional casting and rolling [Shin et al., 1995; Kang, 2000]. The focus is primarily on stainless steel. Davy International, a British engineering firm, was responsible for the design of the hot model [Anonymous, 1993]. In 1994, a pilot caster was constructed [Millbank, 1995]. At the moment no steps have been taken towards the design and construction of an industrial scale caster. Sources at RIST state that the technical problems have been solved on the pilot scale, however, the uncertainties about the techno-economic performance make POSCO refrain from investing in an industrial scale caster [Kang, 2000]. Others speculate that the crises in Asia are discouraging POSCO from engaging in large capital expenditure [Birat, 1999a; Cramb, 2000].

[18] POSCO established RIST in 1987. RIST is a legally independent R&D institute. POSCO supplies 60 to 70% of RIST's total budget [Kang, 2000].

## 5.5. Analysing the development

In mapping this history of strip casting technology we presented elements, which are of interest to our analysis of the case study. First we address the questions formulated about the technology network, then we focus on the various micro-networks and subsequently we discuss the results of the R&D activities.

### Technology network

<u>What is the composition of the technology network?</u>

Before 1975, localised R&D activities were performed by certain individuals the three main ones being Bessemer, Norton and Hazelett. Between 1975 and 1985 a large number of R&D efforts were launched which all tried to extend the advantages of conventional continuous casting to even thinner casting. Different types of casting moulds were explored. There were also a growing number of efforts weighing up the pros and cons of single or twin roll strip casting. By 1985, strip casting R&D efforts were announced in almost each major steel-making country [Cramb, 1989; Cramb, 2000]. By 1990, the strip casting technology network had acquired a clear status. The majority of the R&D efforts were stopped when the decision had to be made to continue R&D and thus to invest in a hot model. The efforts that continued were veiled in secrecy because of the strategic importance of the R&D activities [Senk, 2000]. The eleven micro-networks described in Section 5.4 resulted.

Figure 3 gives the technology network of strip casting technology from 1982 onwards. Six of the eleven micro-networks are still active. Four of the eleven micro-networks stopped their activities. Two micro-networks merged their R&D activities. Eurostrip resulted. Three of the six active micro-networks are operating an industrial scale caster and claim to be ready to launch the innovative process technology.

The eleven micro-networks cover a wide geographic area. Steel firms from the US, Canada, Western Europe, South-Korea and Australia are involved. In four of the eleven micro-networks, co-operating actors within a micro-network come from different countries. The three most advanced micro-networks are located in Japan, Western Europe and Australia.
Japanese and US steel firms were the first to start strip casting R&D efforts during the late seventies [Isenberg-O'Loughlin, 1988; Kubel, 1988; Senk, 2000]. Although Japanese firms are still active in various micro-networks, a substantial number of early Japanese efforts were stopped [Birat et al., 1995; Anonymous, 1993]. They passed the job on to Nippon Steel Corporation, which is by far the largest steel firm in Japan [Cramb, 2000; Birat, 2000]. The US lost its original leading position. Only recently US actors have become active again. A co-operative R&D programme was started by Carnegie Mellon University [Cramb, 1998]. In 2000, the US mini-mill

steel firm Nucor formed a joint venture with the BHP and IHI to commercialise BHP / IHI’s strip casting technology.

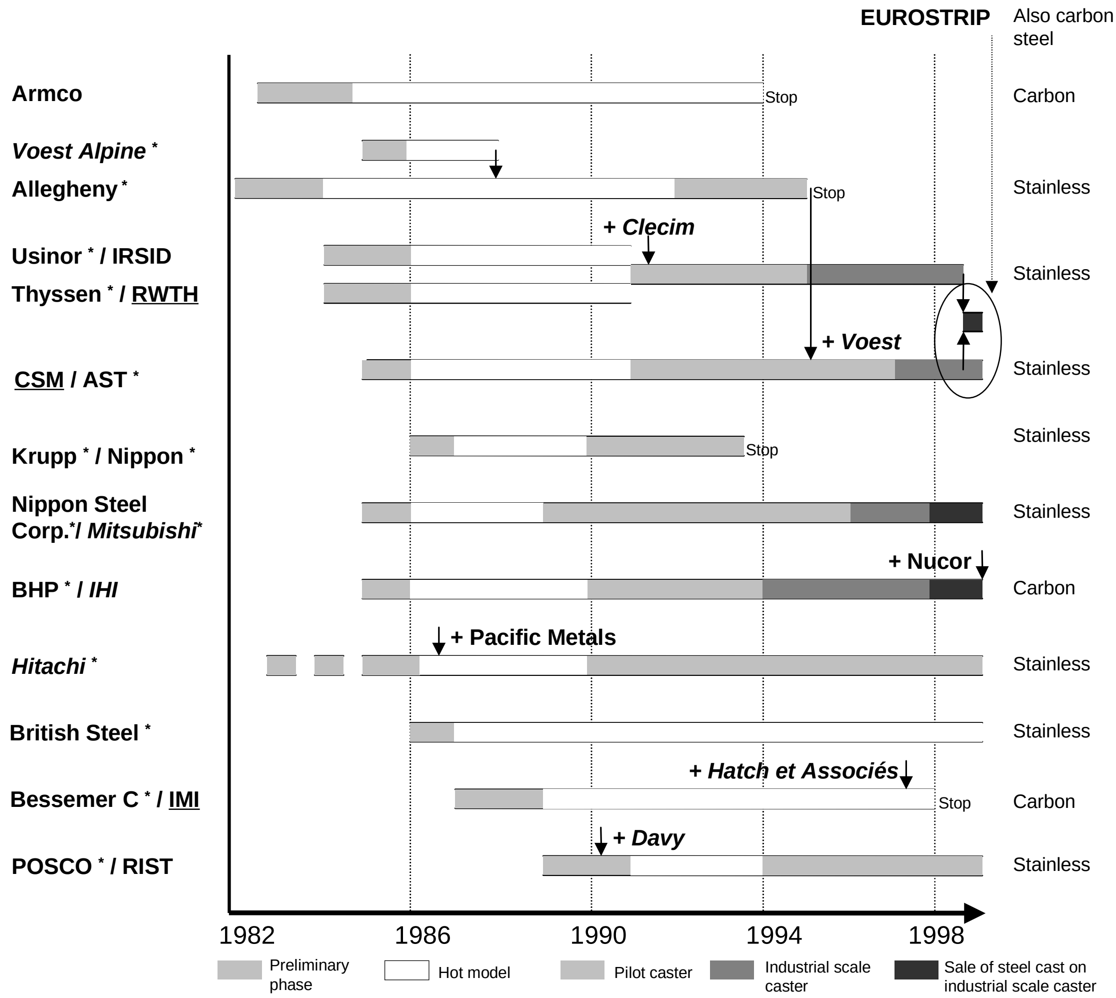


*Figure 3:* *Technology network of strip casting technology. The size of the R&D equipment used – hot model, pilot caster, and industrial scale caster – is included. A preliminary stage and a commercial stage (the steel cast is sold) have been added. The R&D activities of Allegheny and Voest and the co-operation of Thyssen and Usinor are each counted as one micro-network. Actors in normal letters are steel-making firms. Actors in italics are machine suppliers or engineering firms. Actors with underlining are R&D institutes. Asterisks (*) indicate the driving actors within micro-networks.*

<u>To what extent and how often do micro-networks exchange knowledge/information?</u>

In spite of the fact that R&D activities were strategic, there has been exchange and communication between the various micro-networks. In addition to the exchanges at international conferences and meetings there have been more intensive contacts.

Clearly, technical details were generally not disclosed. However, the exchange of knowledge and R&D experience have played a role in the continuation of R&D activities within the various micro-networks [Thompson, 2000; Senk, 2000; Birat, 2000; Cramb, 2000]. It is important to know whether others have succeeded in solving technical difficulties. Then you do not need the details to do the work itself. Furthermore, it is important to know the position of a firm's micro-network among the competing micro-networks for instance to create firm-internal support for continuing R&D activities.

Are there dominant micro-networks in the technology network?

None of the micro-networks had a continuing decisive influence on the development of strip casting technology. There was some early leadership by Allegheny. Their claim of success in 1984 was instrumental in drawing the attention of other steel firms (and their boards of directors) [Birat et al., 1995; Cramb, 2000; Thompson, 2000; Senk, 2000]. For a long time, Allegheny was considered to be the most advanced micro-network (see e.g. [Kubel, 1988; Hess, 1991; Robson and Thompson, 1995]). By the early 1990s, it had become clear that a number of steel firms had invested seriously in developing strip casting technology, although none of them was dominant. In the last two years, it has become clear that there are three front-running micro-networks, Eurostrip, Nippon Steel and Mitsubishi, and BHP and IHI. These three micro-networks may prove the feasibility and advantages of strip casting technology in the coming two or three years. The other micro-networks and the steel industry in general are waiting to see how their casters will perform [Tacke, 1999; Bagsarian, 1998; Cramb, 2000; Senk, 2000].

## Micro-networks

How are the various micro-networks made up?

Figure 3 shows the type of actors that have been involved in the eleven micro-networks. It also denotes who took the initiative in the separate micro-networks.

A first observation is that steel-making firms generally took the lead [Birat et al., 1995]. The machine suppliers, Hitachi, Voest and Mitsubishi, are exceptions. In eight of the eleven micro-networks, a machine-builder or engineering firm became involved in later stages of the R&D activities. In the early eighties it was clear to most actors that it would take time for strip casting technology to be developed and that considerable steel-making expertise was required. This explains why machine suppliers were not pressing for the development of this technology in the way they had pressed for the development of thin slab casting technology [Birat, 1999b].

In developing strip casting technology, control in the various micro-networks is typically exerted by the steel manufacturers. Machine suppliers or engineers were involved when steel manufacturers had the plan to build a pilot or industrial scale caster. However, steel firms own the crucial patents. The suppliers involved are thus

dependent on the steel firms for selling strip casting technology [Birat, 2000; Thompson, 2000; Senk, 2000].
A second observation is that there are no universities in the technology network. The role of research institutes that are financed with public money is also limited; the only ones are the German RWTH and the Canadian IMI. The Italian CSM is a specialised private research firm.

What motivates actors to start and / or stop R&D activities?

Steel firms are interested in strip casting technology mainly because they want to reduce the capital intensity of the steel plant. They want to lower the costs of converting liquid steel to the coiler (see also Figure 1) [Cramb, 1989; Birat et al., 1995; Tacke, 1999; Senk, 2000; Thompson, 2000; Cramb, 2000]. This advantage had been clear to Bessemer. Still, it took more than a century before the technology network emerged.
It took time for steel-makers to recognise the possibilities and advantages of direct casting. This recognition became possible because the industry evolved itself. The steel industry today is not comparable to the steel industry in Bessemer's days. Conventional continuous casting was then not possible. Mini-mills and grades such as stainless steel did not yet exist. When conventional continuous casting matured during the seventies[19], the advantages of skipping even more steps in casting and rolling became apparent, especially to relatively small firms, e.g. stainless steel firms and mini-mills.
Between 1975 and 1985, the search for innovative casting technologies emerged. Technologists and researchers agreed internationally that this was an interesting route [Birat, 1999b]. A process emerged in which the possibilities of such casting technologies were explored. Expectations were confirmed and articulated. The number of R&D efforts increased during the 1980s. A number of factors induced this process: the established need for more compact technologies [Herbertson et al., 1992; Birat 1992]; the availability of research money within steel firms [Birat, 1999b; Cramb, 2000; Senk, 2000], some government R&D support in the US and Europe; and last but not least Allegheny's claim of success in 1984 [Birat et al., 1995]. The production of new grades of steel based on R&D experience in rapid solidification was also feeding the interest in strip casting [McManus and Berry, 1993; Senk, 2000].

[19] Experts indicate that the improvement of conventional continuous casting is continuing. The R&D activities between 1950 and 1980 were so numerous that a wealth of ideas are still available that can improve the costs or quality of conventionally cast steel [ Birat, 1999b; Cramb, 2000; Senk, 2000].

*Table 1: Current status of the eleven micro-networks.*

| **Steel firm** | **Machine supplier or engineer** | **Scale achieved** | **Status** | **Comments** |
|---|---|---|---|---|
| Armco | - | n.a. | Stop 1991 | Armco stopped its single roll caster R&D, because it altered it business policy: carbon steel division was sold. |
| Allegheny | Voest | Pilot | Stop 1995 | Coilcast was not successful enough to justify continued R&D activities. It had taken too long and had proved too expensive. |
| Usinor / Thyssen | Clecim | Industrial scale | Continuation → Eurostrip | After Thyssen's merger with Krupp (1997), the Myosotis project and the Italian micro-network were merged. Eurostrip was formed to achieve industrial maturity and commercialisation. |
| CSM / AST | Voest | Industrial scale | Continuation → Eurostrip | The industrial scale caster at Terni is used by Eurostrip partners for carbon steel strip casting. |
| Krupp / Nippon Metal | - | Pilot | Stop 1992 | After Krupp's merger with Hoesch and problems with the low productivity of the caster and with the quality of the product R&D activities were ceased. |
| Nippon Steel Corporation | Mitsubishi | Industrial scale | Continuation | Current status of R&D is veiled in secrecy. Nippon Steel seem to intend to apply the technology themselves and not to sell/license the technology. Clarity is expected within a year. |
| BHP | IHI | Industrial scale | Continuation | BHP aimed at building mini-mills in South-East Asia. Early in 2000, BHP announced a joint venture with Nucor, a US mini-mill operator, and IHI for further commercialisation. |
| Pacific Metals | Hitachi Zosen | Pilot | Continuation | Problems with edge containment. R&D continues on pilot scale. Future plans are unclear. Some say efforts have ceased. |
| British Steel | British Steel engineering | Hot model | Continuation | After merger with Avesta, arguments for R&D changed. British steel wants to be an "educated customer". |
| Bessemer Consortium / IMI | Hatch et Associes | Hot model | Stop 1998 | None of the firms wanted to invest at the level needed for up-scaling. Three Canadian firms invested in thin slab; and BHP is successful in carbon steel strip casting. |
| POSCO / RIST | Davy | Pilot | Continuation | The Korean economy collapsed; it had become difficult to finance further up-scaling. Uncertainties about the performance make POSCO refraining from investments in an industrial scale caster. |

This combination of mutually reinforcing factors added momentum to the trend and strengthened internal support in steel firms to perform explorative R&D. Integrated steel-firms with a stainless steel division[20] or major independent stainless steel manufacturers[21] continued R&D activities using hot models. As indicated before, a large number of these early strip casting efforts were stopped. The technology network resulted [Birat et al., 1995; Thompson, 2000; Senk, 2000].

In spite of the promising advantages of strip casting a lot of efforts were stopped. The three early explorers of strip casting technology stopped. Most of the efforts that were started in the early eighties and four of the eleven micro-networks ended their strip casting R&D activities. We comment briefly on the arguments for stopping R&D activities.
Bessemer's concluded that his idea was before its time. He also foresaw serious technical difficulties. Both Norton and Hazelett stopped or changed their focus in R&D due to technical problems.
The abandonment of R&D efforts that were started during early eighties is directly related to decision for investing in a hot model. Most firms could not or were not willing to spend the money needed for taking this step [Senk, 2000; Birat, 2000; Cramb, 2000; Thompson, 2000]. Some additional arguments were heard as e.g. we cannot solve technical problems, we are waiting for others to develop, the quality of the steel was uncertain, and finally we stop because others are also stopping [Tacke, 1999; Cramb, 2000]. However, the bottom line was that firms did not want to spend the financial resources required.

Table 1 summarises the status of the eleven micro-networks. It shows that there are two main arguments why actors stopped or slowed down R&D activities. First of all, the budget needed to continue R&D on a larger scale explains why actors lost interest. Secondly, R&D activities were overruled by all sorts of strategic decisions that have nothing to do with the development of the technology as such. However, continuation of R&D activities did become superfluous when for instance divisions or firms were sold, bought or merged.

How much money is spent and by whom?

Table 2 summarises the expenditure on strip casting R&D by the eleven micro-networks as far as relevant data are available. Due to the large differences in the degree of technical complexity of the R&D equipment used it is impossible to give a standard indication of the ratio of the cost of a hot model and the cost of an industrial scale caster. According to rough estimates, an industrial scale caster is 10 to 20 times more expensive than a hot model.

[20] E.g. Nippon Steel Corporation, Usinor, British Steel, Thyssen.
[21] E.g. Allegheny, Nippon Metal, Pacific Metals, AST.

*Table 2: Expenditure on R&D and government R&D support.*

| **Micro-network** | **Scale** | **Total expenditure [M US$]** | **Of which govt. support [M US$]** | **%** | **Government support granted by:** |
|---|---|---|---|---|---|
| Armco[1] | Pilot | 17 | 12 | 70 | US Department of Energy |
| Allegheny[2] | Pilot | 10-15 | - | - | |
| CMU[3] | - | 1 | 0.7 | 70 | US Department of Energy |
| Usinor / Thyssen[4] | Pilot<br><br><br>Industrial | about 10<br><br><br>100 | 1.4<br><br><br>limited | 10-15 | ECSC (see Table 3).<br>Limited support German Bundesländ.<br>French government. |
| CSM / AST[5]<br>Voest | Pilot<br>Industrial | 15-20<br>n.a. | 4.1<br>5 | 20-30 | ECSC (see Table 3).<br>European Commission |
| Krupp Stahl[6] / Nippon Metal | Pilot | n.a. | 0.6 | | ECSC (see Table 3).<br>Limited support German Bundesländ. |
| Eurostrip[7] | Industrial | 50 | - | - | |
| Nippon Steel / Mitsubishi[8] | Industrial | 110 | - | - | |
| BHP / IHI[9] | Industrial | 200 | n.a. | n.a. | |
| Pacific Metals / Hitachi | Pilot | n.a. | - | - | |
| British Steel[10] | Hot model | 4 | 1.7 | 40 | ECSC (see Table 3) |
| Bessemer C / IMI[11] | Hot model | 26 | 13 | 50 | National Resources Canada |
| POSCO/ RIST[12] | Pilot | 20 | - | - | |
| Total | | 570 | 40 | | |
| Total estimate | | 500 – 700 | | | |

[1] Data concerning Armco's private investment in twin roll casting is unknown. [2] In an interview in 1988 Ludlum's chairman said that "of the order of 10 to 15 million US$ worth of investment was paying off in a new process" [Isenberg-O'Loughlin, 1988]. Long running projects like Coilcast involve of tens of million US$ [Hohenbichler, 2000]. [3] CMU = Carneggie Mellon University [Cramb, 1998; Cramb, 2000]. [4] [Birat, 1999a; Birat, 2000; Senk, 2000]. [5] Derived from [CSM, 2000; Cordis, 2000]. [6] [Pfeifer et al., 1993]. [7] [Thyssen Krupp Stahl, 1999]. [8] Only costs of the industrial scale caster [Furukawa, 1997]. [9] [MacLeah, 1998]. [10] Derived from [Thompson, 2000; Cordis, 2000]. [11] [Bagsarian, 1998]. [12] Only pilot caster. Total expenditure is higher but is not made public [Millbank, 1995; Kang, 2000].

Table 2 clearly indicates that micro-networks having an industrial scale caster invested the most. Strip casting experts estimate that expenditure on industrial scale casters is of the order of magnitude of 100 to 200 million US$ (see e.g. [Cramb, 1998; Bagsarian, 1998]). In most of the micro-networks, machine-builders did not make substantial investments, up to 10% [Birat, 1999a]. Only Mitsubishi and Voest were equal partners.

We estimate that worldwide about 500-700 M US$ was spent, which is 35 to 50 million US$ per year. When this is compared to the annual R&D expenditure by the iron and steel industry, we conclude that roughly 1 to 2% of the industry's annual R&D expenditure goes to strip casting technology[22].

What important decisions are made with regard to the direction of technological development?

Each of the eleven micro-networks in Figure 3 had to take two important decisions: the grade of steel and whether to use a single or twin roll mould.
Almost all micro-networks studied strip casting of stainless steel. Only two of the eleven micro-networks focused seriously on carbon steel. Some argued that strip casting of carbon steel was technically more difficult, although it had been primarily an economic incentive that determined the preference for strip casting stainless steel. The relatively small stainless steel firms have the highest capital cost advantage. In addition, the productivity of strip casters (annual output) for large carbon steel manufacturers was too low [Schors, 1996].
When the strip casting technology network emerged during the eighties, the single roll caster was the first and the most seriously studied technology by the two micro-networks in the US. This preference for the single roll caster had to do with earlier experience of rapid solidification research and the wish to develop new steel grades [Cramb, 1989; Birat et al., 1995]. Most of the other micro-networks evaluated both single roll and twin roll casters. The single roll caster lost ground to the twin roll caster. Eight micro-networks preferred twin roll casters, because of their higher productivity and of the possibility to cast steel with symmetric properties [Senk, 2000; Cramb, 2000].

## Materialisation

What is the rate of development and what steps in up-scaling can be distinguished?

Roughly 140 years ago, Bessemer suggested that two rolls could be used as a mould for casting liquid steel. Whereas Bessemer, Norton and Hazelett all had some hot model scale equipment at their disposal, conventional continuous casting and thin slab casting technology were commercialised, before three micro-networks succeeded in bringing strip casting technology almost to the point of innovation. Thin slab casting and strip casting technology both benefited from the renewed interest in casting R&D between 1975 and 1985. When thin slab casting technology was introduced (1989), R&D activities on Hazelett casters was stopped. Strip casting

[22] The iron and steel industry in the US, Canada, Japan, Australia and the EU spent roughly 2.5 billion US$ / year on R&D (1985 – 1994 average) [OECD, 1997]. Note that the budget of the micro-networks working on an industrial caster scale is not supplied by the R&D budget only. It is interesting to compare annual spending on strip casting technology with the budget the governments of IEA/OECD countries spent on industrial energy-efficiency R&D. Over the last 15 years, IEA/OECD countries have spent 220 million US$ per year on industrial energy-efficiency R&D. Average annual expenditure on strip casting is as much as 15 to 25% of the annual government budget on industrial energy-efficiency R&D [IEA, 1997].

technology remained as the sole option to realise direct casting of even thinner slabs. There has been a spurt in developing strip casting technology in the last 15 to 20 years. Figure 3 indicates the steps that various micro-network took in up-scaling strip casting technology. It should be noticed that hot models continue to be used if larger equipment is available. Figure 4 gives the scale of the most advanced equipment used in the eleven micro-networks.

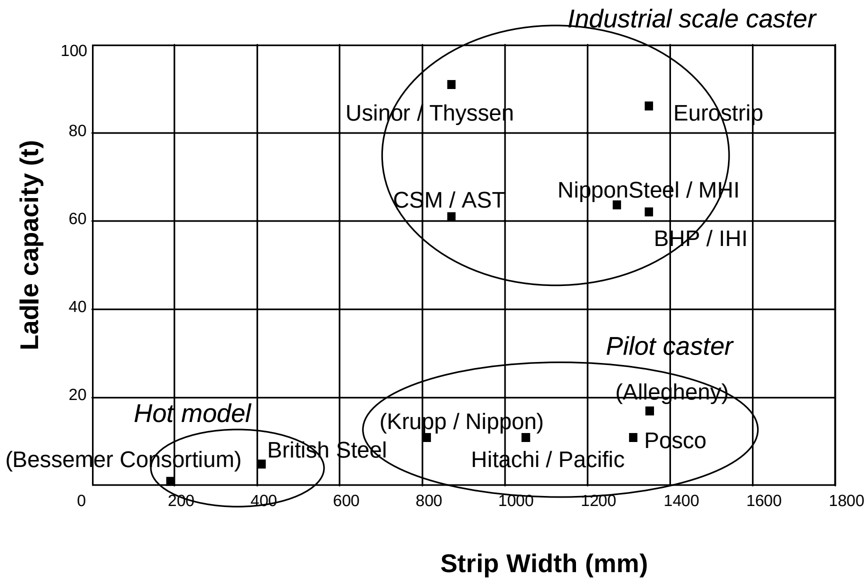


*Figure 4: Cross-section of the development in 1999: showing the state-of-the-art equipment. Three micro-networks operate on near commercial scale: BHP and IHI, Nippon Steel and MHI, and Eurostrip (CSM, AST and Usinor and Thyssen). Firms between brackets indicate micro-networks that stopped R&D activities.*

Figure 3 illustrates that the three most advanced micro-networks all needed 15 to 17 years to reach industrial scale operation. There is some variation in the length of the different stages, though each stage took roughly three to seven years.

Both the Hitachi/Pacific micro-network and the POSCO micro-network continued their R&D activities on a pilot scale for more than six years. British Steel and the Bessemer Consortium have a longer hot model stage; both micro-networks had defensive arguments for investing in strip casting R&D.

What are the perceived performance characteristics of the technology?

Bessemer recognised the capital advantages of his idea [Bessemer, 1891]. An interesting question is whether strip casting could have emerged earlier? On the one hand one can argue that the proven performance of conventional continuous casting and the introduction of thin slab casting (which induced the growth of mini-mills) triggered the need for casting strips of even thinner thickness ranges at even lower

capital costs [Herbertson, 1992]. Strip casting technology became 'the next step to take' since the search routine was to cast as close to final requirements as possible. On the other hand one can say that the existing 'paradigm' of conventional continuous casting may have kept strip casting from taking off earlier.
One should however take into account the fact that two things changed during the last decades of the 20th century. First of all, the industry itself changed considerably: stagnation in world steel output, rapid rise of mini-mills and the introduction of new grades such as stainless steel. Secondly, knowledge became available that could be used to solve the major technical problems, i.e. the liquid steel feeding, edge containment and roll material requirements [Thyssen Krupp Steel, 1999; Birat 2000]. Without the advances in material knowledge (e.g. regarding ceramics and copper alloys) and the availability of computers and process control, it would have been much more difficult to make strip casting an engineering reality [Senk, 2000; Cramb, 2000; Thompson, 2000; Birat, 2000].

The eleven micro-networks did not publish very much about the performance characteristics of strip casting technology. It is clear to all actors that strip casting will lead to lower capital costs and will open the market for cold rolled steel for mini-mills. It is also certain that strip casting reduces the amount of energy needed per ton steel, although this advantage did not drive technological development. The precise cost advantages of strip casting technology are still hidden away among unpublished data [23].

## 5.6. Discussion

For data gathering we were dependent on the information publicly available and on the willingness of experts involved. We tried to acquire a complete collection of written material on strip casting technology and consulted both magazines, journals and conference proceedings. The Corus Library in Ijmuiden was visited.
There are intrinsic shortcomings in the written documentation. First of all, the attention paid to the various micro-networks was not equal. Some micro-networks have been more intensively described in literature. Secondly, the secrecy that surrounds micro-networks make it theoretically possible that micro-networks remain unnoticed in public articles for a long time. An example is that BHP's R&D activities concerned with strip casting became known in 1994, whereas they started in 1985. Thirdly, the information given is sometimes confusing or contradictory. For example the terms used to denote the type of equipment are not uniform, nor are they unambiguous. Fourthly, the issues we are interested are not included in information

[23] The available data on cost performance should be used with care. They reflect what the researchers want the technology to be; crucial estimations had to be made e.g. regarding the costs and life time of refractory materials [Cramb, 2000; Birat et al., 1995].

available to the public. This necessitated personal communication with experts involved.
By interviewing experts we were able to gain a better understanding of the status of the technology network. There are some drawback in interviewing experts like for instance a dependency on experts' willingness (time) and capability (what do they know themselves). Their response is clearly biased by their perception of the development history. Furthermore, experts can only tell what they are allowed to tell. In four micro-networks, personal communication turned out to be impossible. Experts did not respond or were not willing to respond.
However we are convinced that our analysis is robust. We have identified all major micro-networks and have obtained insight into the current leading micro-networks, the actors involved in the eleven micro-networks, their arguments for investing and into the expenditure done.

## 5.7. The effect of government R&D support

Now that we have analysed the historical development of strip casting technology, we focus our attention on the effect of government R&D support. Table 2 showed the financial contribution that government made to various micro-networks. R&D support was granted in the US, Canada and in Europe. In Japan, however, there was no government support. Two-thirds of the European support was channelled via the research programme of the European Coal and Steel Community (ECSC). It should be realised that the R&D budget of the ECSC is raised by a levy on steel prices in Europe and as such cannot be regarded as pure government R&D support.
In this section, we characterise the role and the effect of government R&D support in the US, in Canada and in Europe.

### US

We estimate that financial support by the US Department of Energy (DOE) made up 30 to 60% of the total expenditure there[24]. Government R&D support did not accelerate the technology's development.
The role played by DOE R&D support in the development of strip casting technology can be summarised thus:

- DOE was passive in identifying strip casting technology. Allegheny brought the technology to DOE's attention.
- Allegheny was not interested in obtaining support from DOE because Allegheny was further ahead.
- DOE had a preference for the micro-network of Armco. This effort was focused on carbon steel (bulk grade) and thus promised larger energy savings. DOE felt justified in granting R&D support on the grounds of improving energy efficiency.

[24] Armco micro-network, Allegheny micro-network and the recent CMU project.

- Argonne National Laboratory, financed by DOE, became involved in a consortium of amongst others Weirton and Bethlehem Steel. Argonne had expertise in electromagnetic casting. R&D activities did not materialise.
- During the 1980s DOE supported US Steel first of all in strip casting technology (see Armco micro-network). Having abandoned this effort, US Steel did again succeed in acquiring DOE support, now for developing a Hazelett caster.
- Armco's major argument for abandoning their strip casting project was that all carbon steel divisions had been sold. Therefore, DOE's R&D support did not have any chance of materialising the technology.
- In 1998, Carnegie Mellon University started a multi-partner R&D programme on strip casting technology supported by DOE. The R&D activities permit the actors to become familiar with recent insights in strip casting R&D and the possibilities for application in the US.

## Canada

The Canadian National Research Council supported 50% of the total costs of the multi-year research programme initiated by the Bessemer Consortium and IMI. Government R&D support did lead to additional R&D activities although it did not accelerate the technology's development. The Canadian steel firms aimed at acquiring an understanding of the technology.

## Europe

We estimate that R&D support from the European Coal and Steel Community (ECSC), the European Commission (EC) and some national governments made up less than 10% of the total expenditure on strip casting R&D in Europe[25]. A recent overview of the research areas covered in the ECSC research programme (1986-1999) and a list of funded strip casting projects [Ball, 2000] allowed us to make a more detailed evaluation of the effect of ECSC support on the R&D activities of the European strip casting micro-networks[26].

Strip casting and other casting technologies have been on the agenda of the ECSC since a working group was established in 1985. The Commission and the European steel industry agreed that both conventional continuous casting and new casting technologies were areas of R&D which were important for the modernisation of the European steel industry [Evans et al., 1988; Birat and Steffen, 1991]. Figure 5 gives an overview of the budget spent on casting R&D between 1986 and 1999.

[25] CSM / AST micro-network, Usinor / Thyssen micro-network, Krupp / Nippon micro-network, Eurostrip, and the British Steel micro-network.

[26] A telephonic survey was conducted among the actors involved in ECSC projects (Table 5). The aim was to gain insight into the effect of ECSC R&D support. Claustahl was not consulted because their strip casting projects are not linked to any of the micro-networks. Five actors were consulted. One actor did not want to co-operate. In one case, it was impossible to get in contact with the person's involved in the ECSC projects.

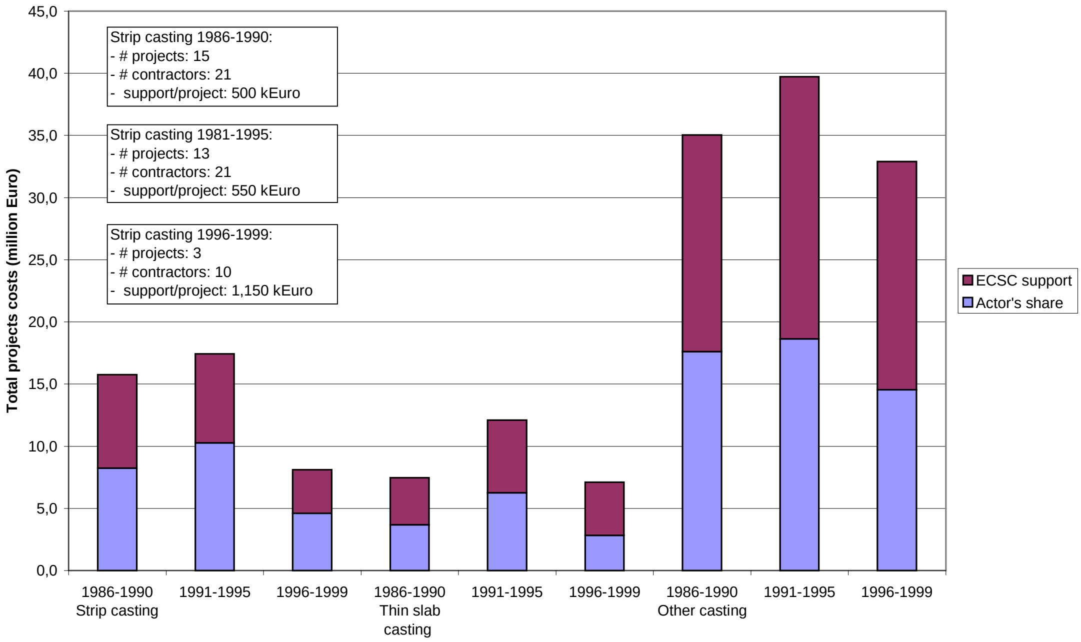


*Figure 5: ECSC support for strip casting, thin slab casting and other casting (mainly conventional continuous casting) in three time-periods. More specific information regarding the ECSC supported strip casting projects is given in the three boxes [Ball, 2000].*

In the period 1986-1999, roughly 2% of the ECSC budget was spent on projects earmarked as ‘strip casting R&D’; 20% of the ECSC’s casting R&D budget was spent on strip casting technology. The ECSC’s strip casting expenditure was about 18 million US$.

Figure 5 indicates that in the last time-period (1996-1999), there was a considerable decrease in the number of strip casting projects. Since the beginning of the 1990s, the European Commission has fostered multi-national multi-partner projects in order to fulfil the requirements of subsidiarity [Ball, 2000]. As a result both the number of partners in strip casting project and the average funding per project increased. These recent multi-national projects are all devoted to *carbon* steel strip casting. This is explained by the simple fact that the steel firms are less willing to co-operate in competitive R&D on stainless steel.

Table 3 shows that ECSC support allowed European research institutes such as Claustahl University and the Max Planck Institute (MPI) to perform strip casting R&D. ECSC support was granted to the UK micro-network of British Steel, the Italian micro-network, and the German / French micro-network in which Thyssen and Usinor co-operated.

*Table 3: Overview of ECSC support (based on [Ball, 2000; Cordis, 2000])[27].*

| **Firm / R&D institute** | **[1]#** | **Total budget [M US$][2]** | **ECSC support [M US$]** | **Time-frame** | **Remarks** |
|---|---|---|---|---|---|
| TU Clausthal | 2 | 0.9 | 0.5 | 1991 – 1995 | |
| MPI | 3 | 1.2 | 0.7 | 1989 – 2000 | |
| VDeH | 1 | 0.8 | 0.5 | 1994 – 1997 | Co-ordinator multi-partner carbon steel project |
| | | | | | |
| British Steel | 5 | 4.0 | 1.7 | 1986 – 2000 | Involved in 2 multi-partner carbon steel projects |
| Thyssen | 2 | 1.1 | 0.6 | 1994 – 2000 | Multi-partner carbon steel projects |
| IRSID (Usinor) | 3<br>2 | 3.8<br>0.6 | 1.4<br>0.3 | 1986 – 1990<br>1994 – 2000 | <br>Multi-partner carbon steel projects |
| CSM | 7 | 11.5 | 4.1 | 1987 – 1997 | EC 4th framework project *NOT* included |
| Krupp<br>KTN (Krefeld) | [3]1<br>2 | 1.4<br>1.5 | 0.6<br>0.7 | 1985 – 1987<br>1991 – 1995 | |
| | | | | | |
| Total | | 27.0 | 11.6 | | |

[1] Number of projects in which the firm or research institute was involved. [2] Assuming 1 US$ ≅ 1 Euro. [3] One project was carried out by Krupp Stahl AG (1985-1887), during Krupp's co-operation with Nippon Metal Industry (Japan). Two projects were performed by Krupp Thyssen Nirosta (KTN) (1991-1995), a sister company of AST. Some people involved in the Krupp / Nippon micro-network were also involved in the activities at KTN.

The R&D activities at Claustahl and MPI were not related to any of the R&D activities in the three European micro-networks. There are no signs that knowledge from Claustahl and MPI has been of major importance for these micro-networks. The Verein Deutsche Eisenhutteleute (VDEh) co-ordinated one of the multi-partner carbon steel projects [Steffen, 2000].

The other actors mentioned in Table 3 were already mentioned in Section 5.4. The Italian micro-network, CSM, received the largest contribution from the ECSC. CSM lost interest in ECSC support when R&D activities moved towards the pilot scale. A similar pattern occurred in the French / German micro-network. There was support for Usinor's IRSID in the early days of the development (until 1990). When the R&D co-operation with Thyssen was started, ECSC support was no longer acquired. British Steel received ECSC support from the start of their efforts up till today. ECSC funds formed a considerable part of the total strip casting budget of British

[27] The ECSC support for the projects in Table 3 is lower than the ECSC support for strip casting mentioned in Figure 5. This is because projects focused on casting in a range of 10 to 40 mm are excluded in Table 3. In Table 3 only two multi-partner projects are included. A third, even more recent multi partner project is not included. Thyssen, IRSID, CSM and British Steel participate in this project which was started in 1998. This project is also for carbon steels. Budget as specified in the contract is 1.7 M US$ of which ECSC support is 1.0 M US$ [Thompson, 2000; Senk, 2000].

Steel, 40% (see Table 2). Without ECSC support, they would have stopped earlier [Thompson, 2000].

We conclude that:

- In the majority of the ECSC R&D projects on strip casting, additionality has been limited. We estimate that 60% of the projects would have been performed anyway.
- Furthermore, the projects that are supported by the ECSC are generally only loosely related to the core of private R&D expenditure on strip casting. ECSC-supported projects cover 'side-lines' of R&D activities. There is a minor chance that spill-over will occur to the core R&D activities.
- For one micro-network, British Steel, it is highly probable that the projects would not have been performed without ECSC support. Activities would also have stopped earlier.
- Steel firms apply for ECSC support in early stages of a technology's development. The steel firms become less interested in ECSC support when development moves towards a larger scale. They then decide to refrain from ECSC support.
- Taking into account the operating procedures of the ECSC research programme and the fact that steel firms determine what kind of R&D projects are supported, we conclude that the majority of the ECSC casting R&D resources are used to optimise conventional continuous casting technologies.
- It is highly likely that the EC demonstration project (Krefeld caster) would have been realised even without EC support of 5 million US$.
- The ECSC supported two multi-partner projects on carbon steel, in which all the major European steel firms involved in strip casting technology micro-networks co-operated. The major gain is that experienced researchers co-operate and have the possibility to learn from each other and share expertise in a pre-competitive area of R&D.

## 5.8. Conclusion

Strip casting technology is at the threshold of becoming a commercialised technology. In this chapter we evaluated the effect of government R&D support on the development of strip casting technology by making a detailed analysis of the networks involved.

Government has supported 5 to 10% of the total expenditure by eleven micro-networks since 1980. Total expenditure by all actors is estimated to be about 500 - 700 million US$. Six of the eleven micro-networks received government R&D support. In three micro-networks R&D support was substantial, more than 40% of total expenditure within that micro-network. Two of these micro-networks stopped R&D activities. The third micro-network continued R&D although intentionally at a

modest scale. Three micro-networks may prove the commercial feasibility of strip casting technology within the next two or three years. These three micro-networks did not receive (or only very minor) government R&D support.
All in all, the effect of government R&D support on the development of strip casting has been minimal. The technology did not become available any earlier as a result of R&D support. Government R&D support did not influence the direction of technological development.

The case study generated convincing evidence for this conclusion. First, R&D support has been minimal or absent in micro-networks that are ahead in developing the technology. R&D support has been the largest in micro-networks that were not operating at the frontier of developing the technology. Steel firms became less interested in government R&D support when activities reached a stage that was more sensitive to competition. Secondly, an analysis of ECSC support to strip casting R&D indicated that about 60% of the projects would have been carried out without that support. Thirdly, government supported R&D projects that addressed ‘side lines’ or that covered pre-competitive co-operative R&D. These were, thus, only loosely related to the core R&D activities. Finally, R&D support did not have a decisive effect in directing technological development to improved energy efficiency. From an energy efficiency point of view, government should have supported the development of carbon steel strip casting technology because of much larger production volumes. Only three micro-networks studied carbon steel intensively. Two of these micro-networks received government R&D support. However, both these micro-networks ceased their R&D activities.

The effect of government R&D support has been minimal mainly because the development of the technology proved to have a strong momentum of its own. After renewed interest in strip casting technology developed between 1980 and 1985, a large number of R&D efforts were started. Strip casting technology promised to extend the advantages of conventional continuous casting. A process emerged in which the possibilities of the technology were explored in a large number of efforts. Expectations were confirmed and articulated. Government R&D support was one of the factors in this process, though it was not decisive. Eleven micro-networks continued their R&D activities. A robust technology network emerged. All micro-networks were initiated and controlled by steel manufacturers. The contribution of public research institutes was very limited. All the steel firms and machine suppliers involved considered strip casting technology as a key-technology for future steelmaking. Strip casting technology affects the core of the steel production process. The dominant advantage, especially for stainless steel producers, is that the technology should make it possible to further reduce the capital investment in hot rolling facilities. Engaging or not engaging in its development is, thus, only loosely related to energy-efficiency improvements or government R&D support.

In our analysis we included not only technical, cost and energy performance characteristics, but we broadened our analysis to include networks of actors. As a result, we could evaluate the effect of R&D support quite accurately. It allowed us to weigh up the effect of R&D support against other incentives that influenced steel firms and machine suppliers to be involved, or to continue or stop. By studying the networks of actors, we were able to sense what might have happened *without* government R&D support.


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# Chapter 6

# Smelting reduction technology

**Abstract**

*Smelting reduction technology is the only recent serious contender to replace the conventional energy-intensive blast furnace that has been the dominant ironmaking technology for centuries. In this chapter we evaluate the effect of government intervention on the development of smelting reduction technology.*

*The theory underlying smelting reduction technology has been known since the 1930s. Only from 1975 did a technology network emerge. By then, other innovative ironmaking technologies had proved disappointing and there was a threat that obsolete coke ovens might have to be replaced at great expense. From 1975 onwards, R&D efforts were undertaken. Only one of these early efforts achieved commercial application, the Corex process. Some efforts evolved into micro-networks that studied 'second generation' processes. The technology network, consisting of nine micro-networks, was heterogeneous. Various types of actors had various technical preferences due to earlier (R&D) experiences. Three micro-networks stopped their R&D activities; these were all initiated by integrated steel manufacturers. They lost interest because the existing capital stock was being continuously improved and they did not need additional ironmaking capacity. Smelting reduction technology was 'locked out'. However, the future of smelting reduction technology is still undecided. Mining firms and steel mini-mills are still interested. The changes in the technology network reflect the dynamics in the development of smelting reduction technology.*

*If we look at the role of government, we find that environmental regulations were not decisive in initiating R&D efforts. The major arguments for R&D were the lower capital costs and the possibility of processing cheaper coals. Reducing environmental emissions and energy-efficiency improvements were only additional reasons for integrated steel firms to be interested. Another conclusion is that financial R&D support enlarged the technology network by supporting processes that were likely to be energy-efficient. However, R&D support did not accelerate the technology development (so far). The case study illustrates that in steelmaking existing capital stock tends to constrain technological development in steelmaking; this considerably limited the effect of government intervention and R&D support.*

## 6.1. Introduction

Improving the energy efficiency of manufacturing industries is considered to be one of the ways to attain a more sustainable use of energy in modern society. Breakthroughs in industrial energy efficiency are appealing to both government and industry; both greenhouse gas emissions and energy costs for making these energy-intensive products are reduced. In the scientific literature on energy efficiency in industry we find detailed overviews of innovative energy-efficient technologies (see e.g. [Martin et al., 2000; De Beer, 1998]). Although these analyses serve the purpose of estimating the long-term potential of energy-efficiency improvement in the industry, they are not sufficient to answer the important question of how the development of such industrial innovative energy-efficient technologies can be enhanced by government. Their strength lies in a detailed bottom-up assessment of relevant characteristics such as energy-efficiency improvement and investment costs. If one wants to enhance the development of such technologies, one needs insight into the actual processes by which such technologies develop. Understanding technological development in terms of networks allows us to assess the importance of government intervention in orienting technological development.

In this chapter we evaluate the effect of government intervention on the development of an energy-efficient technology. For this purpose we make a detailed investigation of the networks in which the energy-efficient technology is developed.

As a case study we selected smelting reduction technology, an innovative technology for the production of iron. The iron and steel industry is a major consumer of energy and is therefore always mentioned as a sector where energy efficiency needs to be encouraged. Both scientific researchers in energy-efficiency analysis and policy makers consider smelting reduction technology to be one of the most important innovative energy-efficient technologies (see e.g. [IWG, 2000; Arthur D. Little, 1998; Martin et al., 2000; De Beer, 1998; IPCC, 2001; AISI, 1998; IISI, 1998]).

This chapter is structured as follows. In Section 6.2, we briefly introduce the two conventional routes for the production of steel. We locate the production of iron as the first and major energy-intensive step in the production of steel and introduce smelting reduction technology as an innovative alternative. In Section 6.3, the technology case study is analysed using a set of questions relating to the networks in which the technology was developed and the materialisation of the technology. This section closes with a short resumé of the current status of the technology network. Section 6.4 analyses in more detail the role of government intervention. The chapter closes with some conclusions about the effect of government intervention in stimulating the development of smelting reduction technology (Section 6.5).

## 6.2. Conventional iron and steel production and smelting reduction technology

### The conventional production routes

The production of iron is the first step in the production process of steel. It is also the most energy-intensive step [Fruehan, 1999; De Beer, 1998; IISI, 1998]. The iron ore is reduced at a high temperature. The iron is subsequently converted into crude steel, cast into semi-finished products (blooms, billets and slabs), and rolled and shaped into final products. There are two major conventional routes for producing final steel products (see Figure 1). Both steel production routes play a role in the development of smelting reduction technology and it is therefore interesting to look briefly at the differences.

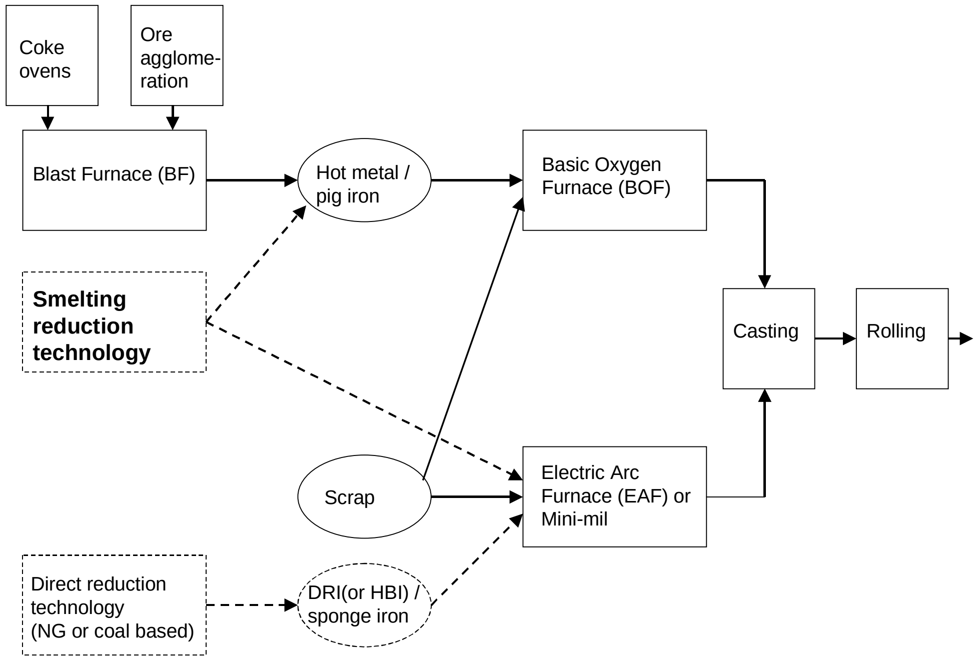


*Figure 1: The two major routes for producing iron and steel: Integrated steel mills and mini-mills.*

The first route is the integrated mill (upper half of Figure 1). Iron ore is reduced in a blast furnace. Coke, agglomerated ore and limestone are charged into the top of the blast furnace. The coke is gasified at the bottom, providing both the reductant (carbon monoxide) and the heat needed for the chemical reactions in the blast furnace. Coke has better physical characteristics for operating the blast furnace and is therefore preferred to coal. One of the major – and for this chapter relevant – improvements in the operation of blast furnaces is that coal is injected directly into the blast furnace, so that less coke is needed for producing hot metal. Both the coke and the agglomerated ore are produced in separate facilities (see Figure 1). The blast

furnace delivers hot metal, which is most often transported to a basic oxygen furnace to produce crude steel. In an integrated mill, high quality steel products can be produced. The annual output of such a mill typically ranges from 2 to 3 million ton steel per year. The specific energy consumption for the most efficient integrated mill is 19 GJ primary energy per ton of crude steel[1]. 85% of this energy is needed for operating the blast furnace (including agglomeration and coke production) [De Beer, 1998]. Cost of coal and other energy sources make up 25 to 30% of the cost of producing one ton of hot metal[2].
The second route is known as a mini-mill (see lower half of Figure 1). In most mini-mills, recycled steel, scrap, is melted in electric arc furnaces and further processed into final products. The mini-mill route has no iron production step and is therefore also considerably less energy-intensive than the traditional integrated mill. The best practice SEC value for a mini-mill is 5 GJ / ton crude steel. Mini-mills generally deliver lower quality steel products. Not all kinds of final products can be made. Its annual output typically ranges from 0.5 to 1.0 million tons steel per year, so mini-mills are considerably smaller than integrated steel mills.

Smelting reduction technology is an alternative technology to the conventional blast furnace. The blast furnace has been the dominant technology for iron production for centuries. Its operation has been improved and optimised continually; this has resulted in very efficient large-scale operating facilities[3]. In addition to smelting reduction technology, direct reduction technology is a second alternative technology to the conventional blast furnace route. Direct reduction technology was explored as a possible replacement for the dominant blast furnace before R&D interest in smelting reduction technology emerged[4].

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[1] The specific energy consumption in integrated mills varies between 19 to 40 GJ per ton crude steel [WEC, 1995].

[2] Literature estimates of the cost price of a ton of *hot metal* range between 120 to 180 US$. Amortisation makes up 30 to 35% of the costs. Costs for iron ore represent 25 to 30% of the cost price of a ton of hot metal. Energy costs represent 25 to 30 % [Astier, 1991; De Beer, 1998]. The energy costs for producing a ton of *steel* are about 10% lower that the energy costs for producing a ton of *hot metal* [Faure, 1993]. The cost price of a ton of *steel* ranges between 200 to 300 US$. The hot metal costs make up a considerable part of the total cost price, 60 to 70%. Mini-mills typically produce crude steel for around 200 US$ per ton [Faure, 1993; Abildgaard et al., 1997; Schors, 1996].

[3] The design of the blast furnace has remained essentially the same since the Stuckoven was introduced in 1300. Charcoal was used as fuel and reductant. Its physical properties limited the capacity of the blast furnace. The physical properties of coke permit larger capacity operation. From 1718 onwards, charcoal was replaced by coke. For a more elaborate description of the improvements in blast furnace technology, see [De Beer, 1998; Chatterjee, 1994].

[4] Whereas the first direct reduction facility was already operational in 1952, it is only recently that direct reduction technology has began to be used on a wider scale. Direct reduced iron (DRI or sponge iron) is increasingly processed in mini-mills, primarily in developing countries where cheap natural gas is available [IISI, 1998; Chatterjee, 1994; Astier, 1991]. Direct reduction facilities are usually not built at the site of mini-mills. They are built at locations were natural gas is cheap. In 1990 about 3.5% of the world-wide iron production was based on direct reduction technology. In 1999, this share has increased to 6.7%. If DRI is used in mini-mills the energy needed for manufacturing steel increases to roughly the same level as in an integrated mill, i.e. 18.5 GJ / ton crude steel (assuming 100% DRI) [De Beer, 1998].

## Smelting reduction technology

Smelting reduction technology is a *coal-based* ironmaking process and thus different from the conventional *coke-based* conventional blast furnace. The production of coke is avoided. Most smelting reduction processes also avoid the agglomeration of iron ore (see Figure 1). Smelting reduction technology, as the name clearly suggests, involves both solid-state reduction and smelting. Smelting is melting involving chemical reduction reactions. Smelting reduction technology exploits the principle that coal can be gasified in a bath of *molten* iron. Figure 2 gives a schematic lay-out of smelting reduction technology.

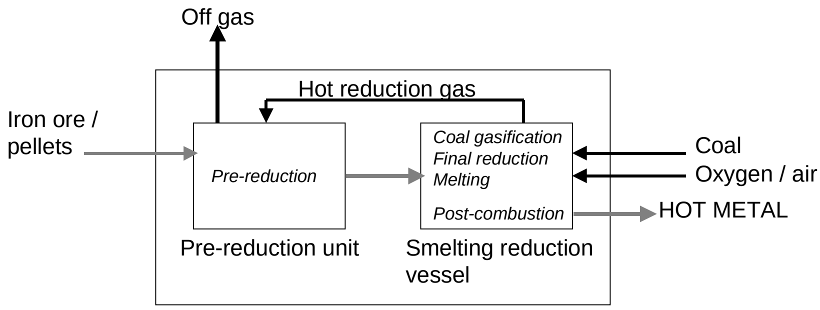


*Figure 2: Schematic lay-out of smelting reduction technology.*

Smelting reduction technology consists of two vessels or two zones, a pre-reduction unit and a smelting reduction vessel (see Figure 2). Smelting reduction technology, however, does not necessarily require two separate vessels. The coal is fed into the smelting reduction vessel where it is gasified. This delivers heat and hot gas containing carbon monoxide. The heat is used for melting the iron in the smelting reduction vessel. The hot gas is transported to the pre-reduction unit and used for pre-reducing the iron oxides (in a solid state), which are fed directly into the pre-reduction unit. The pre-reduced iron is subsequently transported to the smelting reduction vessel, where final reduction takes place.

The hot gas produced in the smelting reduction vessel has a high chemical energy content due to the presence of carbon monoxide. This can be exploited in two ways. Fssirst of all, the carbon monoxide can be used for the reduction of iron oxides in the pre-reduction unit. The hot gas generated in the smelting reduction vessel is transported directly to the pre-reduction unit. Secondly, the carbon monoxide can be oxidised in the smelting reduction vessel, which then delivers more heat. This can be used for smelting the iron. This is called post-combustion. After post-combustion, the hot gas is transported to the pre-reduction unit and the remaining carbon monoxide is used for pre-reducing the iron oxides.

The richness of carbon monoxide in the hot gas determines the degree of pre-reduction in the pre-reduction unit. As post-combustion decreases the reduction potential of the hot gas, compromises have to be made between the degree of post-combustion and the degree of pre-reduction. If the degree of post-combustion is low,

higher pre-reduction degrees are achieved in the pre-reduction unit. The product delivered to the smelting reduction vessel is quite similar to the reduced iron that is produced in direct reduction technology, namely direct reduced iron (DRI). More coal is needed in the smelting reduction vessel to melt the iron. Processes operating at such a high level of pre-reduction are referred to as *first generation* processes. The Corex process is the best known first generation process.
If the degree of post-combustion is high, lower degrees of pre-reduction are achieved. Less coal is needed, because extra heat is generated and used to melt the pre-reduced iron (provided heat exchange is optimised). Processes operating under such a regime are referred to as *second generation* processes [Tomellini, 1994; Poos, 1993].

As will become clear throughout this chapter, smelting reduction technology is not a homogeneous technology. There is a variety of smelting reduction *processes*. In this chapter we discuss the development of ten smelting reduction processes.

## 6.3. Analysing the development

In this analysis, we focus on ten smelting reduction processes which were developed in nine micro-networks. We start by giving a short historical description of the technology in order to illustrate the background against which the technology network emerged. We subsequently focus on the technology network. The technology network is the collection of all the actors who are active in developing a specific technology. A technology network usually consists of a number of smaller micro-networks in which a few actors co-operate. Before we continue with a more detailed analysis of the micro-networks, we look at the materialisation of the technology. We close with a short resumé of the current status of smelting reduction technology.

### The early days

The technology network of smelting reduction technology grew seriously from 1980 onwards, although, the principle of gasifying coal in a molten bath is much older. It was conceived in the late 1930s[5] [Chatterjee, 1994]. In the late 1950 and 1960s, steel manufacturers were interested in developing a technology that could convert iron ore into crude steel in just one step. The principle of gasifying coal in a molten bath was also popular at that time [Smith, 2000; Feinman, 1999; Poos, 1993]. However, attempts to develop direct steel making technology were stopped, on the one hand by

[5] Martin Wiberg in Sweden (1938) injected a mixture of iron ore and coal into an open hearth furnace (steelmaking furnace). The Engell brothers in Denmark (1938-1939) studied a process in which iron ore and coal powder were sprinkled into a moving high carbon bath. The generated carbon monoxide was burned (post-combusted) above the bath [Chatterjee, 1994; Smith, 2000].

the fact that not all technical problems could be solved and on the other hand by the trend in ironmaking towards giant high capacity blast furnaces. The steel industry expanded rapidly. There was a huge demand for higher quality steel products and with the introduction of the basic oxygen furnace for converting hot metal into crude steel (1952), there was a tremendous demand for cheap hot metal. The cheapest way to meet this requirement was to operate large scale blast furnaces [Smith, 2000; Feinman, 1999; Poos, 1993; Smith and Corbett, 1987].
This dominant trend created the opportunity for the development of ironmaking processes, which were economic on a smaller scale. A first contender was gas-based direct reduction technology which gradually emerged from the mid-1960s onwards [Papst, 1987; Smith, 1992; Poos, 1993]. In those days, direct reduction technology was projected as the best possible alternative to the dominant iron production route. However, direct reduction technology did not break through as a serious alternative. Several inherent drawbacks namely the high reactivity of the solid-state direct reduced iron and the high price of natural gas, forced actors to look for alternative coal-based iron production routes [Papst, 1987; Chatterjee, 1994; IISI, 1998].

## Technology network

<u>What is the composition of the technology network?</u>

From 1975 onwards, a new contender appeared on the scene: smelting reduction technology [Smith, 1992; Chatterjee, 1994; Feinman, 1999; Smith, 2000]. R&D activities were undertaken to develop a *coal-based* ironmaking process producing *liquid* iron (or hot metal). The idea was to smelt pre-reduced iron. Between 1975 and 1985 a considerable number of efforts were initiated namely between 15 to 20. The efforts differed primarily in the type of smelting reduction vessel employed for (s)melting a direct reduced iron-like product [Smith, 1992; Smith and Corbett, 1987; Papst, 1987].
Most of the efforts were limited to pilot scale activities and the generation of engineering concepts for industrial scale facilities. There was one exception [Smith, 1992; Feinman, 1999; Scott, 1994]. The German engineer Deutsche Voest[6] and the Austrian machine supplier Voest commercialised the Corex process. A South-African steel maker ordered the first facility in 1985. After two false starts, the facility was handed over definitively to the South African steel firm in 1989[7]. The Corex micro-network is one of the smelting reduction processes included in our analysis (see Figure 3).

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[6] When the R&D activities started, Deutsche Voest was known as Korf Engineering.
[7] The Corex process still requires agglomerated ore. Corex is a first generation process. It has a high degree of pre-reduction. The solid state DRI-like pre-reduced iron is melted in the smelting reduction vessel. Since most of the reduction is done in the solid state, Corex is a slower process than the other smelting reduction processes [Fruehan, 1999]. Due to the Asian crisis, which had a negative impact on hot metal prices in South Africa, the South-African steelmaker Iscor decided to shut down the Corex facility temporarily in 1998 [VAI, 2000].

Three of these early efforts evolved into R&D activities in which actors tried to achieve higher post-combustion levels. The processes with higher post-combustion levels are referred to as second generation smelting reduction processes. As a result the following three micro-networks can be distinguished (see also Figure 3). Some Japanese integrated steel firms continued earlier private R&D activities in the DIOS micro-network [Fruehan and Cramb, 1990; Chatterjee, 1994]. The UK British Steel and the Dutch Hoogovens continued their earlier experiences with smelting reduction in the CCF micro-network in 1989 [Robson, 2000; Meijer, 2000]. The Australian mining company CRA approached the German steelmaker Klöckner Werke, who had already gained experience in smelting reduction processes. The HIsmelt micro-network resulted [Smith and Corbett, 1987; Innes, 2001; Brotzmann, 1992].
In Figure 3, we distinguish five additional micro-networks which developed a smelting reduction process that also involved a high degree of post-combustion [Sarma and Fruehan, 1998; Anonymous, 1996a]. Figure 3 gives a general overview of the technology network from 1980 onwards.

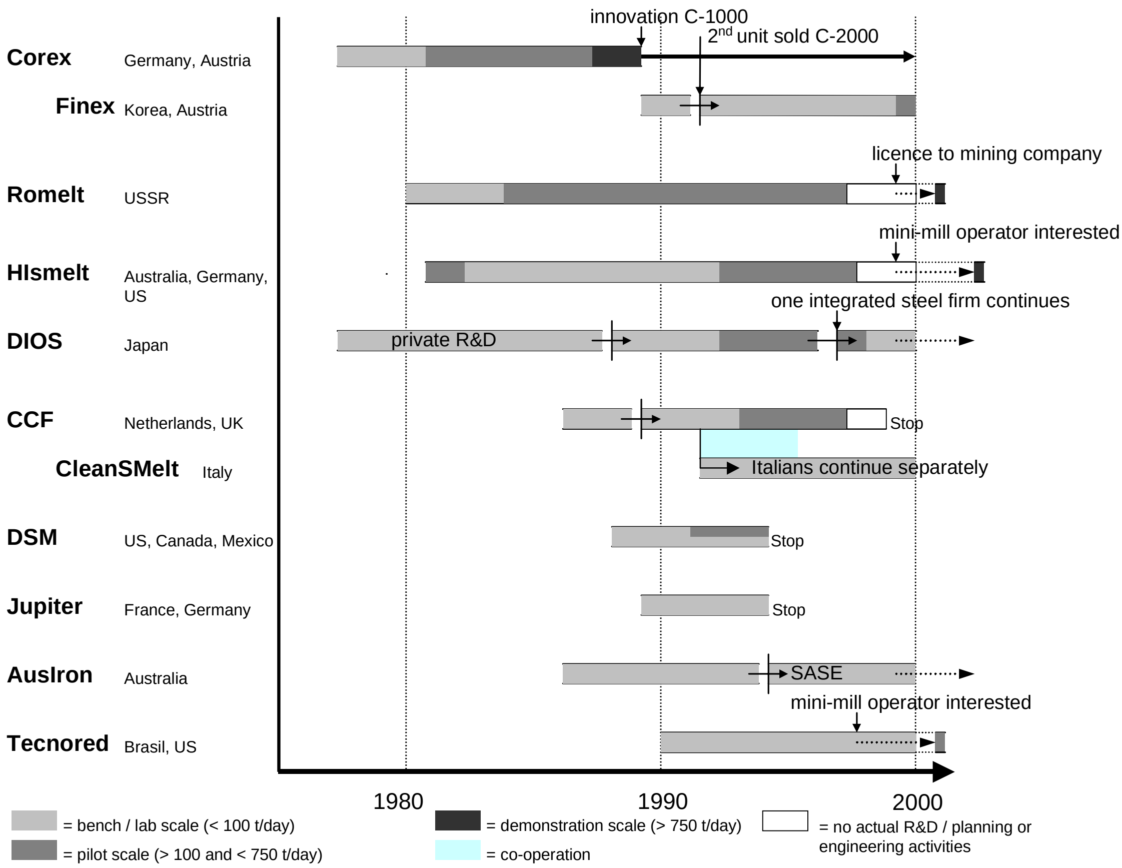


*Figure 3: Technology network of smelting reduction technology. Nine micro-networks developed ten smelting reduction processes. The capacity of equipment is used to denote up-scaling of the technology. For reasons of clarity we did not include all actors in Figure 3, nor did we indicate when certain actors stopped their active R&D.*

Figure 3 shows that the Austrian machine supplier Voest has continued the development of the process after the first Corex facility was realised. Voest and a Korean steelmaker joined forces to develop a variety of the Corex process which could use fine iron ores rather than agglomerated ore. We regard the Corex process and the so-called Finex process as having been developed within one micro-network[8].

Figure 3 illustrates that the nine micro-networks are widely distributed across the world. Two of the micro-networks are based in Australia, one in the former USSR, one in Japan, one in the US, one in Brazil and three in Europe.
Six of the nine micro-networks are still active, one of them being the Austrian machine supplier Voest. In two of these six micro-networks, after a period in which R&D activities were stopped, interest by external actors induced renewed (R&D) activity. This happened in the Romelt and HIsmelt micro-networks [SAIL, 2000; Kemp, 2000; HIsmelt, 2000; Anonymous, 2000a]. In the Tecnored micro-network there is a plan to build a pilot facility in 2001 [Anonymous, 2000b; Ritt, 2000]. In the DIOS micro-network and the AusIron micro-networks, actors intend to develop the process further[9].

Three micro-networks stopped their activities. Integrated steel manufacturers initiated these three micro-networks. None of the micro-networks merged. Only the CCF micro-network branched in 1992, from then onwards the Dutch and the Italians continued the development of the same process separately[10].

[8] The argument for regarding the Finex process and the Corex process as one-micro-network is that the developments are very closely related. Whereas POSCO had started R&D activities towards smelting reduction technology in 1989, they could not have undertaken the development of Finex without Voest. POSCO started R&D activities relating to smelting reduction technology as one of the long-term R&D projects that began when POSCO decided to expand its R&D capacity in order to improve the firm's competitive operation [Shin, 2000]. The Austrian machine supplier Voest had already filed some patents in the area of pre-reducing iron ore fines instead of agglomerated ore [Eberle et al., 1996; Delport, 1991]. The Korean steelmaker POSCO bought the second Corex facility. Its capacity was twice the capacity of the first Corex facility in South-Africa. Voest installed three more Corex C-2000 facilities, two in India and one in South-Africa.

[9] In the *DIOS micro-network*, the Japanese integrated steel manufacturer NKK is trying to commercialise DIOS technology independently. NKK wants to exploit its expertise and tacit knowledge in designing and operating the DIOS process. NKK wants to transfer the technology to other firms. A first DIOS facility of 4,500 thm/day is expected for mini-mills in a few years [Kitagawa, 2000]. A facility of 40 thm/day recently became available in the *AusIron micro-network*. The SASE joint venture regularly states that they plan to build a 7,000 thm/day facility. Note that Ausmelt Ltd., the engineering firm in the SASE joint venture, has experience in commercialising the technology for non-ferrous metals [Arthur and Floyd, 1999; Arthur and Hamilton, 1996; Sherrington, 2001].

[10] Note that we regard the CCF micro-network as being no longer active. The Italians however are still working on the development of the cyclone. They changed the name of the CCF process to CleanSMelt [Anonymous, 1997b; Malgarini et al., 1996]. The Italians were not willing to co-operate in our research for reasons of confidentiality.

To what extent and how often do micro-networks exchange knowledge?

In the development of smelting reduction technology, the various micro-networks performed R&D activities on their own, although each of the micro-networks closely monitored the developments within the entire technology network. In several cases, results of other micro-networks influenced decisions and R&D activities [Meijer, 2000; Fruehan, 2000; Burrow, 2000; Lassat de Pressigny, 2000]. The most far-reaching example in this regard is the Dutch Hoogovens decision in 1992 to restrict R&D to the pre-reduction unit only. After reviewing worldwide ongoing smelting reduction efforts, Hoogovens concluded that the cyclone was unique. It was decided to use all financial resources for building a pilot scale cyclone. If the cyclone proved satisfactory, Hoogovens would start looking for a partner to 'complement' the process [Meijer, 2000; Moors, 2000b].
The major arguments for exchanging knowledge are to learn from the solutions suggested by others and to avoid repeating their mistakes and re-inventing the wheel [Burrow, 2000; Robson, 2000; Meijer, 2000; Lassat de Pressigny, 2000; Floyd, 2000]. Usually articles, conference visits and patents are a first source. If R&D activities seemed of to be real interest for a firm's R&D activities, personal contacts were established and site visits were organised. There was for instance regular contact between the North-American Steel association AISI and its Japanese counterpart JISF for the development of DSM and DIOS [Kavanagh and Obenchain, 2000; Kitagawa, 2000]. People from the Dutch Hoogovens and AISI visited the Russian Moscow Institute of Steel and Alloys (MISA), which developed the Romelt process. Hoogovens also visited JISF once [Furukawa, 1994]. JISF held several technology exchange meetings, and also met representatives from the Jupiter process [Kitagawa, 2000; Badra, 1995]. The Australian mining firm developing the HIsmelt process also had personal contacts with other micro-networks [Burrow, 2000].

Are there dominant micro-networks in the technology network?

In the development of smelting reduction technology, none of the nine micro-networks had a decisive influence on the entire technology network. None of the micro-networks set the rate and direction of the technology development. Although the Corex process is the first smelting reduction process that became commercially available, its general applicability was limited. To avoid this, the later second generation processes tried to achieve higher levels of post-combustion [Lassat de Pressigny, 2000; Sarma and Fruehan, 1998; Chatterjee, 1994; Astier, 1991].
The lack of dominance is due partly to the variety in the types of pre-reduction units and smelting reduction vessels, the different ways chosen to optimise either post-combustion or pre-reduction, and the variety of vessels used in various smelting reduction processes. Smelting reduction technology is not a homogeneous technology.

## Materialisation

What is the rate of development and what steps in up-scaling can be distinguished?

In this section we focus on the materialisation of the technology in order to see how many years were needed to develop smelting reduction technology. Figure 3 indicated the number of years that micro-networks actors were active. Figure 4 gives a more detailed account of the capacity of the equipment used in R&D.
If we glance at Figure 4, it becomes clear that most of the processes are operational on a relatively modest scale. In some micro-networks there are plans for taking the next step, although such plans do not give any guarantee. The plan to build a HIsmelt facility on the site of a US mini-mill steel manufacturer has recently been postponed till at least 2003.
Figure 4 indicates that steps in up-scaling the technology differ among the various micro-networks. We can only give a rough indication of the difference in scale that is a factor 5 to 10 between the subsequent steps.
Figure 4 also demonstrates that it is difficult to generalise about the time frame needed for developing smelting reduction processes, primarily because nine of the ten processes are not yet operational on a near-commercial or demonstration scale. At the moment only the Corex process is commercially available. Roughly ten years were needed to make the first Corex facility run satisfactorily on a scale of 1,000 thm/day. More than fifteen years were needed to make it operational at 2,000 thm/day[11]. Figure 4 indicates that two processes might become operational on a demonstration scale in the near future. In both these cases, at least 20 years were needed to reach the status of materialisation.
A final interesting observation was made in the CCF micro-network; historic decisions on the materialisation of the CCF process likely affected its later development. Hoogovens and the Italian integrated steelmaker Ilva have separately continued R&D since 1992 (see Figure 4). The major reason was that the firms could not agree on where to build a new pilot research facility. Meijer (2000) speculates that if the firms would have continued co-operation and if they would have built a complete smelting reduction process – including both the pre-reduction unit and the smelting reduction vessel –, the course of events might have taken a more positive direction. Such a complete facility might have delivered results that would have enhanced the decision to build a demonstration facility between 1995 and 1999. As shown Figure 4 and as will be discussed in a later section, the demonstration facility was not built.

If we look at the up-scaling of the processes (Figure 4) and at the time frames of active R&D (Figure 3), we conclude that it takes at least 10 to 20 years to perform the necessary steps. In this estimate, we did not take into account the delay caused by the shelving of some of the processes.

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[11] The C-3000 with a capacity of 3,500 – 4,000 thm /day is currently up for ssale [VAI, 2000].

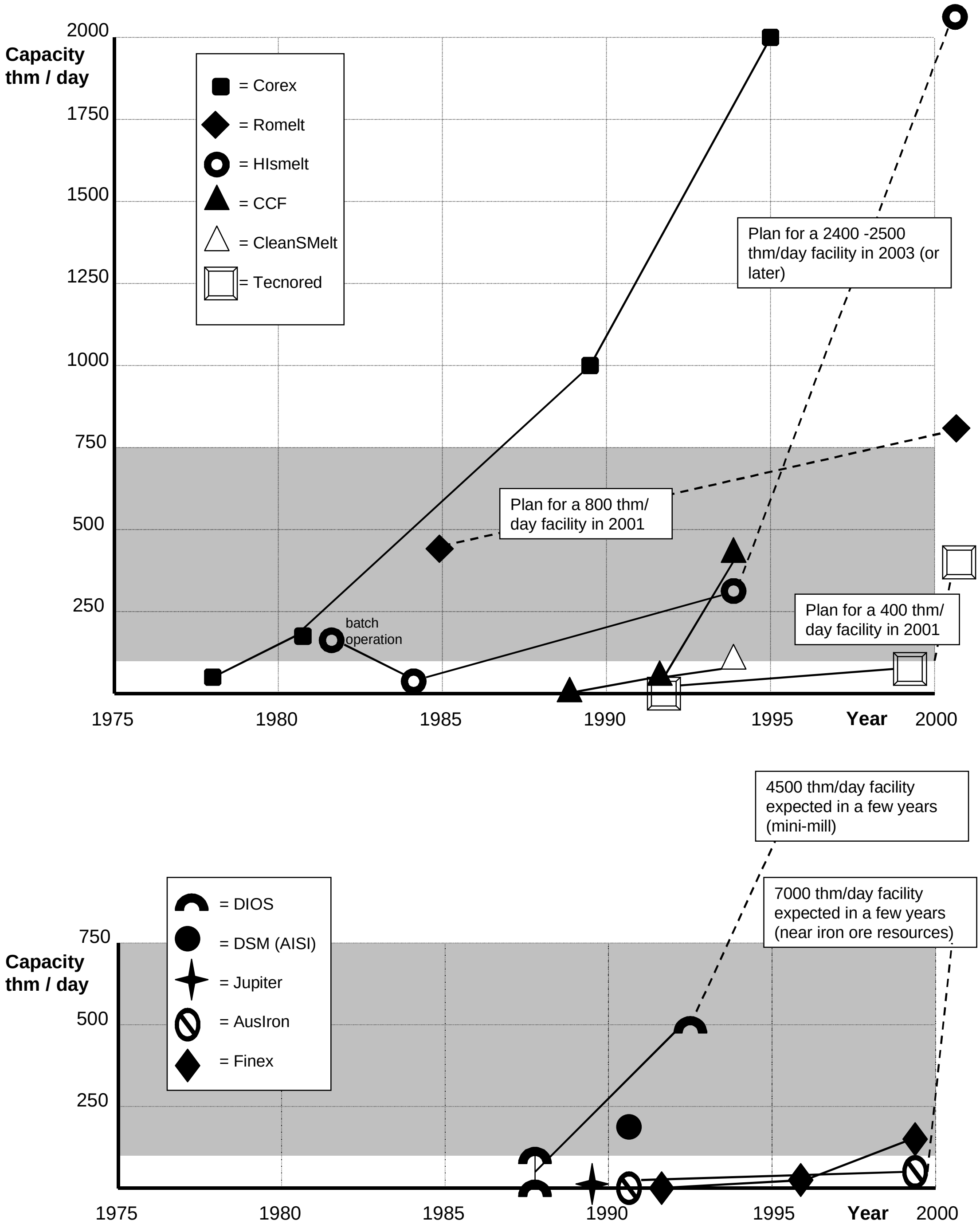


*Figure 4: The steps taken in up-scaling the ten smelting reduction processes*[12].

[12] The scale of equipment or facilities is usually expressed in tons of hot metal per day (thm/day). There is however no uniform standard regarding what is a near-commercial scale or demonstration facility, a pilot facility or a lab scale facility. Whereas Hoogovens considered a 1,400-2,000 thm/day facility as a demonstration facility, the Corex facility in South Africa is seen as the first commercial facility, i.e. 1,000 thm/day. On the other hand, the recent AusIron facility of 40 thm/day is referred to as a demonstration facility. We make a distinction between lab / bench scale facilities, which are <100 thm/day; pilot scale facilities, which are >100 and <750 thm/day; and demonstration or near-commercial scale facilities, which are > 750 thm/day.

What are the perceived performance characteristics of the technology?

Smelting reduction technology overcomes some major disadvantages of the conventional blast furnace route for iron production. This causes that the cost price of a ton of hot metal is likely to be reduced [Smith, 2000; Kitagawa, 2000]. This is the most important characteristic of smelting reduction technology.

Lower capital investment (avoiding coke ovens and agglomeration plants and replacing the capital intensive blast furnaces) and the use of coal instead of expensive metallurgical coals are two major factors in this cost price reduction. Smelting reduction technology is cost competitive even on a relatively small scale in that it increases operational flexibility. Smelting reduction processes also show a larger flexibility in the type of raw materials that can be processed. Finally, smelting reduction technology has clear-cut environmental advantages over the conventional blast furnace route [Pollock, 1995; Millbank, 1995; Fruehan, 1999; De Beer, 1998; IISI, 1998].

Whereas some performance data can be found in the literature, these merely affirm what was formulated in more general terms in the former paragraph. Only the Corex data are backed up by industrial operation. The other performance data found represent targets for pilot or demonstration facilities under construction but are not an elaborate account on what was actually measured in R&D. The ranges reflected in e.g. cost price data found are largely due to differences between smelting reduction processes[13].

The performance data reported for smelting reduction technology are promising – in fact they form the core arguments used by actors to legitimise their investments in developing smelting reduction technology –. However, it is difficult for the technology to compete with the conventional increasingly optimised and very efficient blast furnace route. Most often the performance data quoted in the literature do not reflect the competitive position very accurately. By now, most of the smelting reduction processes seem to have lost ground to the incrementally improved conventional route for producing iron. For a more elaborate discussion of these changing circumstances we refer to the next section in which we discuss some arguments put forward for stopping the development of smelting reduction technology in various micro-networks.

[13] In literature we found that estimates of a cost price reduction varied from +10 to -25 US$ per ton hot metal (after off gas-creditation) [Anonymous, 1996b; Meijer et al., 1994; Furukawa, 1994]. In literature the cost price of a ton hot metal in a smelting reduction ranges from to 80 to 160 US$ [Weston and Thompson, 1996; MacCauley and Price, 1999; Dry et al., 1999; Meijer et al., 1996; Abildgaard et al., 1997].

## Micro-networks

How are the various micro-networks made up?

Table 1 gives an overview of the composition of the nine micro-networks. Table 1 clearly illustrates that a wide variety of actors played a role in the nine micro-networks. A variety of types of actors also initiated the R&D activities.
In four of the nine micro-networks, integrated steel manufacturers took the lead. In the North American DSM micro-network an association of steel companies played an important role in initiating R&D activities (AISI). Machine suppliers or engineering companies initiated three micro-networks, mining firms initiated two micro-networks and research institutes initiated one micro-network. Note that the micro-network that was initiated by a research institute operated in the former USSR planned economy [Pokhvisnev, 2000].
It is interesting to compare this variety with the composition of the micro-networks developing strip casting technology. In the development of strip casting technology, another important innovative energy-efficient technology, steel manufacturers generally took the lead and controlled the R&D activities. Steel manufacturers initiated ten of the eleven micro-networks (see Chapter 5). The larger variety of actors involved in developing smelting reduction technology clearly has to do with the position of the technology in the steelmaking process. Production of hot metal is also interesting for mining firms or for engineering companies who have an existing technology that can also be used for smelting iron. Only in one micro-network a well-known machine supplier to the iron and steel industry initiated the R&D activities, i.e. the Austrian machine supplier Voest.

Table 1 makes a distinction between the role of integrated steel manufacturers (column 3) and the role of the so-called mini-mill operators (column 2). In three of the five micro-networks in which integrated steel manufacturers did *not* take the lead, mini-mill operators became involved when the technology was claimed to be ready for operation on an industrial scale (see also Figure 3).

The second column of Table 1 gives a detailed overview of which actors played a role in developing smelting reduction processes. With the exception of Romelt's micro-network[14], in all the micro-networks various actors co-operated in developing smelting reduction technology.

[14] The Russian steel firm Novolipetski Metallurgical Kombinat (NLMK) was appointed by the USSR government as host for the pilot facility (450 th/day) and a commercial facility (2,500 thm/day). After the fall of the former USSR regime, the Russian economy collapsed and there was no need for additional ironmaking capacity. The commercial facility was never built [Valavin and Pohvisnev, 2000; Thompson, 2000].

*Table 1: Overview of all the actors in the technology network. ♦= Actor that initiated R&D activities; • = Other actors.*

| Process | Actors | Country | Supplier / engineer | Mini-mill steelmaker | Integrated steelmaker | Research institute | Government | Mining company | Steel association |
|---|---|---|---|---|---|---|---|---|---|
| Corex | Deutsche Voest | Germany | ♦ | | | | | | |
| Finex | Voest | Austria | ♦ | | | | | | |
| | Iscor (1984-1989) | South-Africa | | • | | | | | |
| | POSCO + RIST (1992-now) | Korea | | | • | | | | |
| Romelt | MISA | Russia | | | | ♦ | | | |
| | USSR government | Russia | | | | | ♦ | | |
| | NLMK | Russia | | | • | | | | |
| | ICF Kaiser (licence 1995) | US | • | | | | | | |
| | Nippon Steel Corp. (licence 1995) | Japan | | | • | | | | |
| | NMDC (licence 2000 / via RSIL) | India | | | | | | • | |
| HIsmelt | CRA | Australia | | | | | | ♦ | |
| | Klöckner Werke (1981-1987) | Germany | | | • | | | | |
| | Midrex Corporation (1989-1994) | US | • | | | | | | |
| | CSIRO (early 1990s) | Australia | | | | • | | | |
| | Nucor (1999-now) | US | | • | | | | | |
| DIOS | Japanese steel firms (1988-1996) | Japan | | | ♦ | | | | |
| | JISF (1988-1996) | Japan | | | | | | | • |
| | NKK (1997-now) | Japan | | | • | | | | |
| CCF | British Steel (1989-1992) | UK | | | ♦ | | | | |
| CleanSMelt | Hoogovens (1989-1999) | Netherlands | | | ♦ | | | | |
| | CSM (1989-now) | Italy | | | ♦ | | | | |
| | German research institutes (94-97) | Germany | | | | • | | | |
| DSM[1] | Canadian, US and Mexican steel | Canada, US, | | | ♦ | | | | |
| | firms (1988-1995) | Mexico | | | ♦ | | | | |
| | AISI (1988-1995) | US | | | | | | | ♦ |
| | Research institutes and universities | US | | | | • | | | |
| Jupiter | Usinor | France | | | ♦ | | | | |
| | Lurgi | Germany | • | | | | | | |
| | Thyssen (1993 – 1994) | Germany | | | • | | | | |
| AusIron | Ausmelt Ltd. | Australia | ♦ | | | | | | |
| | AuIron Energy | Australia | | | | | | ♦ | |
| | Ministry for Mines and Energy | Australia | | | | | • | | |
| | Krakatau Steel (1997-now) | Indonesia | | | • | | | | |
| | Australian universities | Australia | | | | • | | | |
| Tecnored | Tecnologos | Brazil | ♦ | | | | | | |
| | North Star (1998-now) | US | | • | | | | | |
| Initiators (counted per micro-network) | | | 3 | - | 4 | 1 | 1 | 2 | 1 |
| Total number of actors involved (counted per micro-network) | | | 6 | 3 | 8 | 5 | 2 | 3 | 2 |

[1] The US government had a role in preparing the legal framework through which a co-operative R&D programme could be established between public and private actors. The so-called Steel Initiative through which government aimed at promoting long-term R&D in the steel industry paved the way for the development of the DSM process in a co-operative R&D programme [Kavanagh and Obenchain, 2000; Sharkey, 1998; Badra, 1995].

In seven of the eight micro-networks co-operation was established right from the start. In the four micro-networks which were initiated by integrated steel manufacturers ‘competing’ steel firms co-operated. In two of these micro-networks, the North-American DSM micro-network and the Japanese DIOS micro-network, a larger number of integrated steel manufacturers co-operated (with substantial R&D support from the government) in developing smelting reduction technology.
We asked the experts what the actors’ arguments were for co-operating in the micro-networks. They gave two major arguments: sharing the R&D expenditure and creating access to specific knowledge or earlier R&D experience [Burrow, 2000; Kitagawa, 2000; Fruehan, 2000; Meijer, 2000; Robson, 2000; Kavanagh and Obenchain, 2000; Lassat de Pressigny, 2000; Birat, 2000; Floyd, 2000; Freydorfer, 2001].

What motivates actors to start and / or stop R&D activities?

To supplement the knowledge gained from articles, conference papers and journal articles, we asked the experts why actors became actively involved in developing smelting reduction technology. By discussing these arguments with the experts it was possible to get a better idea of what really got them moving. Table 2 gives an overview of each of the actor’s arguments for initiating or becoming involved in the development of smelting reduction technology.

Table 2 shows that actors’ arguments differ per ‘type’ or ‘category’ of actor. Mining firms are interested primarily in exploiting existing deposits. Smelting reduction technology allows them to give added value to their raw materials or waste products. Table 2 illustrates that mini-mill steel makers showed interest in smelting reduction processes at a moment when the processes could be applied on a scale suitable for electric arc furnaces. Whereas the South-African Iscor was interested in applying the first Corex facility because of their limited access to metallurgical coals in South-Africa, the major argument why mini-mill operators were interested in smelting reduction technology was that it guaranteed a fixed priced supply of high quality hot metal. Feeding a mini-mill with hot metal increases the productivity and also opens up possibilities for the production of higher quality products. Table 2 shows that it was primarily the wish to reduce the cost of producing a ton of hot metal which caused the integrated steel manufacturers to be interested. Avoiding capital expenditure on new coke ovens (and also blast furnaces) and the possibility of using relatively cheap coals (instead of scarce and expensive metallurgical coals) were the two major factors in this cost price reduction. The threat of environmental regulations and the necessity to invest in order to comply with these requirements delivered an additional cost advantage.

*Table 2: Actors' arguments for being involved.*

| Type of actor | Actor | Micro-network | Replace obsolete coke ovens (and BF) | Coal instead of metallurgical coal | Flexibility (operation + raw material) | Environmental emissions | Low cost hot metal | High-quality hot metal supply EAF | New process in portfolio | Broaden application existing process | Exploit deposit (coal or iron) | Obligation / deal with government |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inte-grated steel-maker | Klöckner[1] | HIsmelt 1981 | | • | | | | | | | | |
| | Japanese firms[2] | DIOS 1988 | • | • | • | | • | | | | | |
| | NKK[3] | DIOS 1997 | • | • | • | • | • | • | • | | | |
| | Nippon Steel | licence Romelt 95 | | • | | | • | | | | | |
| | British Steel[4] | CCF 1989 | • | • | | | • | | | | | |
| | Hoogovens[5] | CCF 1989 | • | • | | • | • | | | | | |
| | Ilva/CSM[6] | CCF 1989 | • | • | | • | | | | | | |
| | North-American Firms[7] | DSM 1988 | • | • | • | • | | | | | | |
| | Stelco[8] | DSM 1994 | | | • | | • | | | | | |
| | Usinor[9] | Jupiter 1989 | | | | | • | • | | | | |
| | POSCO + RIST[10] | Corex/Finex 1992 | • | • | | • | • | | | | | |
| Mini-mill steelmaker | Iscor[11] | Corex 1984 | | • | | | • | • | | | | |
| | Nucor[12] | HIsmelt 2000 | | | | | • | • | | | | |
| | North Star[13] | Tecnored 1998 | | | | | • | • | | | | |
| Machine supplier or engineer | D Voest + Voest[14] | Corex 1989 | | • | | | | | • | | | |
| | ICF Kaiser[15] | licence Romelt 95 | | | | | | | • | | | |
| | Midrex[16] | HIsmelt 1989 | | • | | | • | | • | | | |
| | Lurgi | Jupiter 1989 | | • | | | | | • | • | | |
| | Ausmelt Ltd.[17] | AusIron 1986 | | | | | • | | • | • | | |
| | Tecnologos[18] | Tecnored 1990 | | | | | | | • | • | | |
| Research institute | MISA[19] | Romelt 1980 | | • | • | | | | | | | |
| Mining firm | NMDC[20] | licence Romelt 00 | | | • | | | | | | | • |
| | CRA[21] | HIsmelt 1981 | | | • | | • | • | | | • | • |
| | AuIron Energy[22] | AusIron 1995 | | | | | • | | | | • | |

[1] [Burrow, 2000]. [2] [Kitagawa, 2000; Furukawa, 1994]. [3] [Takahashi et al., 1990; Kitagawa, 2000]. [4] [Robson, 2000]. [5] [Meijer, 2000; Moors, 2000a; Boom, 1998; Dekker and Knol, 1996]. [6] [Malgarini et al., 1991]. [7] [Badra, 1995; Kavanagh and Obenchain, 2000; Thompson, 2000; Fruehan, 2000]. [8] [Ritt, 1998a; Kavanagh and Obenchain, 2000; Thompson, 2000]. [9] Usinor's major aim was to develop competence [Lassat de Pressigny, 2000; Lassat de Pressigny, 1993]. [10] [Shin, 2000; Lee et al., 1999; Schenk et al., 1998]. [11] [Merwe et al., 1989; Millbank, 1995; Eberle et al., 1996; Freydorfer, 2001]. [12] [Anonymous, 2000a; Kemp, 2000]. [13] [Ritt, 2000; Anonymous, 1997c; Ritt, 1997]. [14] [Freydorfer, 2001; Smith and Corbett, 1987; Delport, 1991]. [15] [Thompson, 2000]. [16] [Burrow, 2000]. [17] [Floyd, 2000]. [18] [Pokhvisnev, 2000; Valavin and Pokhvisnev, 2000; Vildanov et al., 1998]. [19] [Poos, 1993]. [20] The Romelt facility is aimed at processing iron ore slimes, a waste product of mining activity. There is an agreement with the state government to use off gases for electricity generation [Pokhvisnev, 2000; SAIL, 2000]. [21] CRA agreed with the Australian government to establish added value economic activity [Innes, 2001; Burrow, 2000; Dry et al., 1999; Prideaux, 1996; Innes, 1995]. [22] [Floyd, 2000].

It is interesting to take a closer look at British Steel's and Hoogovens' arguments for becoming involved in smelting reduction technology. First of all, their arguments are fairly typical for the other integrated steel manufacturers. The promising reduction in the costs of producing a ton of hot metal made these firms go into action in 1986. The need to reduce costs guided R&D decisions. Secondly, it is almost paradoxical that the circumstances that allowed the start-up of the CCF development in 1989 later caused the CCF process to be shelved (in 1999).
In 1986, British Steel and Hoogovens started to develop the CBF process, a predecessor of the CCF process (see also Figure 3). Both firms were interested in developing this coal-based CBF process so that they could move away from reliance on coke ovens and avoid huge capital investments and the use of expensive metallurgical coals. Reducing the cost of a ton of hot metal was the major driving force. In 1989, R&D activities concentrated on CCF. The major argument for this change was that the cost advantage of the CBF process over the conventional route turned out to be modest. On the hand this was caused by the technology itself; agglomeration was still needed. But the improvements in the existing iron production route had also improved the coke situation in both firms. So in 1989 there was *time left* to switch R&D to a more explorative new process that promised even larger reductions in the cost price of hot metal by avoiding agglomeration of the ore. However, ongoing improvements in the existing coke ovens and blast furnaces in both firms eventually led to the shelving of the CCF process [Robson, 2000; Meijer, 2000; Boom, 1998; Dekker and Knol, 1996; Moors, 2000a].
The circumstances that permitted the switch from the CBF process to the CCF process in 1989 – in a way Hoogovens' and British Steel's 'escaped to the future' – turned out to be the major reason why integrated steel manufacturers lost interest in smelting reduction technology.

Table 3 gives an overview of the actors who ceased being active role in developing smelting reduction technology. If we compare Table 2 and Table 3 we conclude that it was primarily integrated steel producers who ended their involvement. The major argument was that they no longer had the need to replace obsolete conventional coke ovens (and possibly blast furnaces) early 21st century. And secondly, the integrated steel manufacturers, all of whom operated in industrialised countries, did not need additional ironmaking capacity [Sexton, 2000].
It became unnecessary to replace existing coke ovens and blast furnaces due to a number of reasons. The introduction of pulverised coal injection in the blast furnace reduced the need for coke in hot metal production in integrated steel works. Most of the integrated steel manufacturers invested in R&D concerned with pulverised coal injection at the same time as they were active in developing smelting reduction technology. This reduced the pressure on the existing coke ovens. Furthermore, the steel firms succeeded in upgrading and improving the existing coke ovens so that their lifetime could be extended. The possibility of importing coke from e.g. China further relieved the pressure on coke production. Furthermore, new and cleaner coke ovens were developed and offered for sale (and implemented). Finally, the existing

blast furnaces were also continually improved. This resulted in a higher productivity, longer lifetimes and a lower demand for coke for the production of hot metal. Not all these reasons were equally important for each of the integrated steel manufacturers in Table 3. However, all in all, the improvements in the existing capital stock and conventional technology were so large that the cost advantage of the innovative smelting reduction technology became smaller and smaller as time went on.

*Table 3: Overview of actors' arguments for stopping their R&D activities.*

| Type of actor | Actor | Micro-network | Bankruptcy / Restructuring / Merger | No need to replace coke ovens | No need for additional or new iron capacity | Other capital investments | Capital investment / performance | Research completed | No (external) financial resources |
|---|---|---|---|---|---|---|---|---|---|
| Integrated steel-maker | Klöckner[1] | HIsmelt 1987 | • | | | | | | |
| | Japanese firms[2] | DIOS 1996 | | | • | | | • | |
| | British Steel[3] | CCF 1992 | | • | • | | | | |
| | Hoogovens[4] | CCF 1999 | • | • | • | • | • | | |
| | North-American firms[5] | DSM 1994 | | • | • | • | • | • | |
| | Stelco[6] | DSM 1995 | | | | | • | | |
| | Usinor [7] | Jupiter 1994 | | | • | • | | | |
| Machine supplier or engineer | ICF Kaiser[8] | licence Romelt 99 | • | | | | • | | |
| | Midrex[9] | HIsmelt 1994 | | | | | | • | |
| Research institute | MISA[10] | Romelt 1980 | | | | | | | • |

[1] [Burrow, 2000]. [2] [Kitagawa et al., 1999; Kitagawa, 2000, Fruehan, 2000]. [3] [Smith, 2000; Robson, 2000; Meijer, 2000; Millbank, 1995; Tomellini, 1994]. [4] [Meijer, 2000; Dekker and Knol, 1996; Roggen, 2000]. [5] [Kavanagh and Obenchain, 2000; Ritt, 1998a]. [6] [Meijer, 2000; Kavanagh and Obenchain, 2000; Fruehan, 2000]. [7] Both Thyssen and Usinor recently invested in new coke oven capacity [Birat, 2000; Lassat de Pressigny, 2000]. [8] A small subsidiariy of ICF Kaiser filed for bankruptcy. The firm was sold in separate parts [Thompson, 2000]. [9] [Burrow, 2000]. [10] [Thompson, 2000].

Lassat de Pressigny (2000), who led the development of the Jupiter process stated: "*The current situation in coke oven and blast furnace operation shows that huge investments in smelting reduction process would have been premature. Smelting reduction was possibly studied at the wrong time*". Smith (2000), who has been well informed about the technology network since the technology network emerged (see

e.g. [Smith and Corbett, 1987]), phrased it like this: *"To put it really simplistically*[15]*: at the moment smelting reduction technology R&D efforts were started the technology was expected to be needed in 10 years. This has not changed".*
One of the integrated steel manufacturers did not stop its R&D activities. The Japanese firm NKK is still active in trying to commercialise DIOS technology. Kitagawa (2000) stated: *"Only recently we engineered a revised process using DIOS …, which attracted the interest of several steel makers. We are having intensive and serious discussions with them. Smelting reduction technology must be one of the right answers for the future".*

In general, however, integrated steel manufacturers stopped their activities because they could not foresee any opportunity for smelting reduction technology in the near future. The expenditure needed for developing the processes was simply too high to continue without any applications in sight [Meijer, 2000; Smith, 2000; Lassat de Pressigny, 2000; Kavanagh and Obenchain, 2000; Fruehan, 2000; Sexton, 2000].

<u>How much money is spent and by whom?</u>

Table 4 (see next page) summarises the expenditure on developing smelting reduction technology.

Table 4 does not indicate expenditure data for all micro-networks. The data available point to roughly 550 million US$. We estimate that the total expenditure lies somewhere between 600 and 700 million US$.
The expenditure for bringing strip casting technology towards commercialisation (per micro-network) is of a similar order of magnitude[16] (see Chapter 5).

<u>What important decisions are made with regard to the direction of technological development?</u>

As was indicated before, the variety of smelting reduction processes is rather large. There is simply no single technological origin of smelting reduction technology. The technical roots are quite diffuse (see e.g. [Sarma and Fruehan, 1998; Anonymous, 1996a; Ritt, 1996]). Various micro-networks made rather deviant decisions regarding their R&D activities.

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[15] In the context of replacing existing blast furnaces in companies like his own (British Steel, UK). Additional ironmaking capacity is not required.
[16] Note that over the last 15 years, the IEA/OECD countries spent on average 220 million US$ per year on industrial energy-efficiency R&D [IEA, 1997]. Annual expenditure on developing smelting reduction technology has been about 30 to 45 million US$ per year.

*Table 4: Expenditure on R&D and government R&D support.*

| **Process** | **Cap. [thm/ day]** | **Total [M US$]** | **Of which: gov. support [M US$]** | **%** | **Government R&D support granted by:** |
|---|---|---|---|---|---|
| Corex[1] | 1,000 | n.a. | n.a. | n.a. | German Ministry of Research + Technology<br>Austrian Research Promotion Foundation |
| Finex | 150 | 40 | - | - | - |
| Romelt[2] | 450 | n.a. | n.a. | n.a. | USSR government |
| HIsmelt[3] | 300 | 200 | - | - | tax deduction |
| CCF[4] | 400 | 18 | 7 | 40 | European Coal and Steel Community ECSC |
| DIOS[5] | 500 | 150 | 100 | 67 | MITI / DIOS R&D programme |
| NKK | | 26 | - | - | - |
| DSM[6] | 160 | 60 | 46 | 77 | US Department of Energy / DSM |
| | | 8 | 6 | 70 | US Department of Energy / waste oxides |
| Jupiter[7] | 8 | > 10 | 0.25 | < 5 | European Coal and Steel Community ECSC |
| AusIron[8] | 40 | 40 | 6.5 | 20 | Australian Federal Government<br>South-Australian Government |
| Tecnored[9] | 50 | n.a. | n.a. | n.a. | Brazilian government |
| Total | | 550 | 165 | 30 | |
| Estimated range | | 600 - 700 | | | |

[1] n.a. = no data available. Freydorfer (2001) and Shin (2000) do not comment [Anonymous, 1997d; Smith and Corbett, 1987]. [2] Valavin and Pokhvisnev (2000) do not comment. [3] Burrow (2000) does not comment. Estimate comes from [Badra, 1995] and [Cusack et al., 1995]. [4] Total expenditure includes the R&D activities of British Steel, Hoogovens and CSM performed in three ECSC supported projects [Meijer, 2000; Robson, 2000; Cordis, 2000]. [5] [Furukawa, 1994; Kitagawa, 2000]. [6] The DSM R&D programme evolved into a programme that used the pilot facility for testing the reduction of waste oxides. AISI is obliged to repay DOE's contribution from the net proceeds of commercialisation (R&D support + 50%). If AISI refuses to commercialise the DSM process, the patent rights are forfeited to DOE [Kavanagh and Obenchain, 2000]. [7] Usinor acquired ECSC support for one project (1992-1995). This project's budget was less than 5% of Usinor's total expenditure [Lassat de Pressigny, 2000; Cordis, 2000; Birat, 2000]. [8] [Floyd, 2000; Sherrington, 2001]. [9] [Poos, 1983].

Looking at the energy-efficiency of the various processes, we can distinguish three categories[17]. The first category consists of the Corex process. Its high-degree of pre-reduction, makes it a relatively energy-intensive process. The second category consists of second generation processes, which consist of one vessel; these are the processes known as Romelt, Ausmelt and Tecnored. They tend to have a high specific energy consumption [Sarma and Fruehan, 1998; Chatterjee, 1994; Anonymous, 1996a]. The third category includes second generation processes, which consists of a pre-reduction unit and a smelting reduction vessel; such as HIsmelt, DIOS, CCF and DSM[18]. These four 'converter-based' processes aim to optimise the

[17] The Jupiter process does not fit into any of these categories (see e.g. [Poos, 1993]).

[18] Note that the HIsmelt process can also operate as a one-vessel process. The productivity/economics improve significantly by coupling it to a pre-reduction unit. Note that the CCF process consists of one vessel. However, in the vessel a pre-reduction zone (the cyclone) and a smelting reduction zone can be distinguished. The difference between CCF and the other one-vessel processes is that in CCF the degree of post-combustion can be controlled.

exchange of heat, which is generated by post-combustion, back into the smelting reduction vessel [Scott, 1994].

The preference of various actors for the different processes can be explained by their earlier (R&D) experiences with (parts) of the smelting reduction processes.
Both Deutsche Voest and Voest sold natural-gas-based direct reduction technology. They were thus familiar with the ‘shaft furnace’ they adopted as a pre-reduction unit. They were also familiar with highly pre-reduced iron. All three one- vessel processes, Romelt, AusIorn and Tecnored, derived from an ‘existing’ smelting technology. The actors had been involved in developing these preceding smelting processes [Floyd, 2000; Poos, 1993; Pokhivisnev, 2000]. The four ‘converter-based’ second generation smelting reduction processes all evolved from integrated steel manufacturers’ experiences with converter operations (e.g. the addition of coal in steel converters to increase scrap processing) [Smith and Corbett, 1987; Brotzmann, 1992; Robson, 2000].
These converter-based second generation smelting reduction processes are the most interesting from an energy-efficiency point of view[19]. To decrease coal input by optimising heat exchange was an explicit R&D criterion in developing these processes. However, in two of these micro-networks R&D activities were stopped. The application of the HIsmelt process by the US mini-mill operator Nucor would not be an energy-efficient application if hot metal is replacing scrap[20]. It remains to be seen whether and where NKK succeeds in commercialising the DIOS process.

## Resumé

Smelting reduction technology is not yet a proven technology. Only one of the nine micro-networks succeeded in bringing a specific smelting reduction process to the market, although this specific process lacks general applicability and has a high specific energy consumption. In five of the eight additional micro-networks R&D activities are still going on. However, the composition of the technology network has changed over time.
Most of the integrated steel manufacturers who played an active role in various micro-networks lost interest in smelting reduction technology. Existing blast furnaces and coke ovens were continually improved and the lifetimes of the existing stock was extended. The threat that obsolete coke ovens and blast furnaces would have to be replaced did not (yet) come true. They did not need an expansion of their iron production capacity. Smelting reduction technology was ‘locked out’ by a

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[19] In 1998, IISI expected that the specific energy consumption of smelting reduction technology would be of the same order of magnitude as an optimised blast furnace. Dispensing with coke ovens and sinter plants makes smelting reduction technology overall more energy-efficient [IISI, 1998].
[20] If a smelting reduction unit is implemented in a mini-mill, hot metal can be supplied to an electric arc furnace, so that the furnace’s power consumption for melting the raw material will decrease. Its productivity will increase. It overall specific energy consumption will increase if it *replaces* scrap as raw materials. If hot metal replaces direct reduced iron (DRI), specific energy consumption is likely to decrease slightly.

continuous, incremental improvement of the conventional production route and the existing capital stock.
However, the future of smelting reduction technology is still undecided; actors like mining firms continue to be interested and there is a growing interest of mini-mill steel operators. Application of smelting reduction technology in mini-mills may be a short-term niche for proving the feasibility of some of the smelting reduction processes. A successful introduction of smelting reduction technology in mini-mills may enhance the market position of the mini-mill route.

## 6.4. The effect of government intervention

In this section we focus on the effect of government intervention on the development of smelting reduction technology. We analyse the effect of environmental regulation and government R&D support. We discuss the role of stimulating co-operation in various multi-actor micro-networks. Finally, we focus on the support that government intended to give in connection with the building of two demonstration facilities.

### Environmental regulations

In countries like the US, Canada, Japan, Australia and in Western Europe industry is confronted with regulations regarding environmental emissions in the production of iron. Coke ovens and sinter plants are most affected [Hogan and Koelbe, 1994; EIPPCB, 1999; Prabhu and Cilione, 1992]. The environmental advantage of smelting reduction technology over the conventional route is generally articulated by all actors involved in developing smelting reduction technology (see e.g. [Sexton, 2000; HIsmelt, 2000; VAI, 2000; AISI, 1998; Weston and Thompson, 1996]).
We asked the experts whether the environmental emissions had been a decisive argument for initiating or performing R&D activities. The need to comply with environmental regulations was usually indicated as one of the factors leading to the cost advantage of the smelting reduction technology over the conventional blast furnace route. If smelting reduction technology were be applied, other environmental investment would not be needed. However, this incentive would never have been large enough to initiate huge and technologically complex R&D efforts such as the development of smelting reduction technology[21]. As was indicated before, avoiding capital expenditure and using cheaper coals were the two main factors in favour of

[21] The importance of such environmental regulations in driving R&D differs among the technologie sunder development. Hoogovens was the first to apply Emission Optimised Sintering (EOS) technology on a commercial scale primarily because it had to reduce environmental emissions of sulphur dioxide and nitrogen oxides. Lurgi (Germany) originally developed EOS. EOS allows the re-use of the flue gas that is released during the sintering process (agglomeration of iron ore). The investment in the EOS facility was easily recouped through savings on energy costs [Meijer, 2000; Moors, 2000a].

smelting reduction technology. The environmental advantage of smelting reduction processes was clearly taken into account, although it was a modest part of the overall (cost) considerations [Smith, 2000; Kavanagh and Obenchain, 2000; Kitagawa, 2000; Robson, 2000; Meijer, 2000].

Waste disposal regulations in the US are such that land-filling is increasingly taxed [Weston and Thompson, 1996; Anonymous, 1996c; Kavanagh and Obenchain, 2000; Thompson, 2000]. This tax on waste disposal makes it attractive for integrated steel manufacturers to recycle waste material from steel sites. It is interesting to note the following two observations from the empirical material.
First of all, the US engineering firm ICF Kaiser International tried to enter this 'niche' of recycling waste oxides. They wanted to offer a smelting reduction process as a commercial product in their engineering activities. Although ICF Kaiser did not succeed in applying the Romelt process on a commercial scale[22], this example shows that actors actively use niches created by government intervention for extending and strengthening their business.
Secondly, these waste disposal regulations were influential in the continuation of the co-operative R&D programme for developing the DSM process. At the end of the R&D programme in 1994, the steel association managed to mobilise R&D support from the government for continuing R&D activities. In view of the fact that the steel firms were not really enthusiastic about up-scaling the DSM process, continuation of R&D was an non-committal next step [Thompson, 2000; Ritt, 1998b; Nelko, 1994; Fruehan, 2000]. Continuing R&D was a fruitful strategy in postponing large capital investments.

With regard to the effect of regulations we come to the following conclusions:
- Environmental regulations were not critical in initiating the development of smelting reduction technology, not did they affect the R&D decisions taken. However, they provided researchers and engineers within a firm with an additional argument for continuing R&D.
- Environmental regulations were not selective. They did not favour the development of smelting reduction technology over the conventional technology (nor did they prevent steel firms from investing in new coke ovens)[23].

## Government R&D support

We now look more closely at what effect government R&D support had on stimulating the development of smelting reduction technology. Government

[22] ICF Kaiser acquired a licence for the Russian Romelt process in 1995. ICF tried to sell the Romelt process by claiming it could process waste disposal and waste oxides in integrated steel plants [Weston and Thompson, 1996]. There are a number of reasons why ICF Kaiser's attempt failed. The process turned out to be a 'rough diamond'. The process required further development. ICF Kaiser did not have the financial resources. They did not succeed in finding a partner. Furthermore, the steel industry itself was reluctant to invest in high-risk projects [Thompson, 2000].
[23] See [Lassat de Pressigny, 2000; Birat, 2000; Kavanagh and Obenchain, 2000; Ritt, 2000]).

supported R&D activities financially in eight of the nine micro-networks (see second column in Table 5). Two micro-networks received R&D support through the Research Technology and Demonstration programme of the European Coal and Steel Community (ECSC). The budget for the RTD programme comes from a levy on the steel price, so it is not government R&D support in a strict sense. Table 4 gives a more detailed account of government's contribution to the total expenditure in the separate various micro-networks. Table 4 shows that government support has been substantial in developing the DIOS process, the CCF process and the DSM process.

For evaluating the effect of government R&D support on the development of smelting reduction technology, we make a distinction between additionality, acceleration and effectiveness. Additionality indicates whether R&D support led to activities that would not have been undertaken without government R&D support. Acceleration indicates whether R&D support led to an accelerated materialisation of the technology *within the entire technology network*. Effectiveness indicates whether the innovative smelting reduction process may lead to improvements in energy-efficiency once the technology is applied commercially.

*Table 5: Effect of external / government R&D support.*

| **Micro-network** | **Was there external R&D support?** | **Did R&D support lead to additional R&D activities?[1]** | **Did support lead to an acceleration of the technology's development?** | **Will the process improve energy-efficiency?** | **Scale of the process** | **Micro-network still active?** |
|---|---|---|---|---|---|---|
| Corex / Finex | Yes | No | - | No | Innovation | Yes |
| | | | | | | |
| Romelt | Yes | Yes[2] | No | No | Pilot | Yes |
| HIsmelt | No | - | - | Likely | Pilot | Yes |
| DIOS | Yes | Very likely | Maybe | Likely | Pilot | Yes |
| CCF | Yes | Yes[3] | No | Likely | Pilot | No |
| DSM | Yes | Yes | No | Likely | Pilot | No |
| Jupiter | Yes | No[3] | - | Likely | Lab | No |
| AusIron | Yes | Yes[4] | No | No | Lab | Yes |
| Tecnored | Yes | n.a. | n.a. | No | Lab | No |

[1] Assessment based on [Freydorfer, 2001; Burrow, 2000; Floyd, 2000; Lassat de Pressigny, 2000; Meijer, 2000; Robson, 2000; Fruehan, 2000, Ritt, 2000; Thompson, 2000; Kitagawa, 2000; Kavanagh and Obenchain, 2000]. [2] The Romelt process was developed in the former USSR. When the USSR collapsed, government R&D support came to an end [Valavin and Pokhvisnev, 2000; Thompson, 2000]. [3] R&D support through the European Coal and Steel Community (ECSC). [4] The South Australian government has a direct stake in the SASE joint venture which is responsible for developing the AusIron process. The ministry for Mines and Energy of South Australia is no longer a partner in SASE, though the joint venture owns the rights to explore the government's iron ore deposits [Floyd, 2000; Meekatharra, 1998].

Additionality

The assessment of the additionality of R&D support is a first and crucial step. We asked experts about the importance of external support in initiating and continuing

R&D support. We tried to verify their statements by asking other experts. We were able to understand and evaluate experts' responses in the light of their arguments for investing in R&D and of their drive for up-scaling the technology. The second column in Table 5 shows our assessment.

It is plausible that in five of the eight micro-networks R&D support was additional; in these micro-networks government R&D support has been important in initiating or continuing R&D activities. As is indicated in Table 5, in two of these micro-networks external support was 'special'. The Russian Romelt process was developed in the former USSR. In the case of the AusIron process, the South-Australian government wanted to exploit its iron ore deposits and generate added-value economic activity in the region.

In both the North American and Dutch micro-networks, R&D support was important in starting and continuing the R&D activities. The US government played an active role in establishing the legal framework which allowed co-operative R&D programmes. The R&D programme for developing the DSM process was one of these. The Steel Initiative of the US Department of Energy stimulated co-operative R&D between public and private actors to support the deteriorated R&D in the steel industry [Kavanagh and Obenchain, 2000; Sharkey, 1998]. The financial support was a motivating factor for the actors – AISI, the steel firms and some research institutes – to get together and initiate R&D[24] [Kavanagh and Obenchain, 2000]. The ECSC support had an additional role in the development of the CCF process. Cost sharing by the ECSC made it easier to continue R&D at the moment when British Steel and Hoogovens ceased the development of the CBF process and continued with the CCF process in 1989 [Meijer, 2000; Robson, 2000].

With regard to the Japanese micro-network, it is likely that government R&D support led to additional R&D activities. Government R&D support allowed the micro-network of Japanese integrated steel manufacturers to continue former private R&D activities and to build a pilot scale facility on a reasonable scale. After the co-operative DIOS R&D programme was finished NKK continued. The comments of NKK's Kitagawa illustrate that it is not easy to assess additionality. Kitagawa (2000) states that NKK 'probably' would not have continued R&D either. *"The reason why I write 'probably' is that when we carried out our own development we were in the middle of an economic bubble. So we might have spent additional budget to demonstrate the process" [Kitagawa, 2000].*

Acceleration

We can assess whether R&D support accelerated a technology's development by comparing the materialisation of a specific process within the framework of the entire technology network. Only the Corex process achieved innovation (see column six in Table 5). Corex, however, is a first generation process.

If we leave out the Corex process, it is rather difficult to assess whether government R&D support did actually accelerate the materialisation of the technology, because the majority of the efforts has not reached the scale of a demonstration facility and,

[24] It took two years to develop the proposal for the R&D programme.

more importantly, a number of efforts were stopped. The HIsmelt process and the DIOS process are the most likely to become a near commercial facility in the next few years (although no firm decisions have been taken yet). The HIsmelt process was developed without any government R&D support. Because the R&D efforts in developing the DSM process and the CCF process have both been shelved, it is only in the case of the Japanese R&D activities that government R&D support may possibly result in 'accelerated' development of the second generation processes.

Effectiveness

Finally we take a look at the effectiveness of R&D support. An evaluation in terms of energy-efficiency is still speculative; most of the processes did not prove operation on a near commercial scale. We conclude that government had an additional effect on three of the five micro-networks that were developing smelting reduction processes that were likely to be energy-efficient (if it may come to commercial application).

With regard to the effect of government R&D support we conclude that:

- Government R&D support enlarged the technology network, but did not accelerate technology development. Government R&D support did not play an additional role in developing the two processes that had reached the most advanced stage of materialisation so far.
- However, government did play an additional role in expanding the number of micro-networks that invested in developing smelting reduction processes and that were likely to be energy-efficient.

### Stimulating co-operation

The DSM and DIOS micro-networks received substantial R&D support from the US and Japanese government, namely 75 and 67% respectively. In both these micro-networks a large number of actors in a competitive relationship, co-operated. The CCF micro-network received substantial support from the European Coal and Steel Community's RTD programme, roughly 40%. The ECSC's RTD programme stimulates co-operative projects and also obliges the participants of various supported projects to meet and exchange R&D results. Because stimulating co-operation is widely acknowledged as an interesting way for stimulating technological development, these 'network' aspects of R&D support in this case study are commented upon briefly.

As was already indicated, the so-called Steel Initiative in the US made it possible for the Department of Energy to stimulate co-operative R&D between public and private actors. The philosophy was that co-operation among steel manufacturers and research institutes would enhance the effect of the public money spent. In the case of the DSM R&D programme, the possibility of co-operation seemed to provide an opportunity to explore the possibilities of the technology (at a relatively low cost stake for each of the separate firms). The actors were not really seriously interested in investing in the commercialisation of the technology [Freuhan, 2000; Thompson, 2000; Ritt, 1998b].

The Japanese co-operative R&D programme relating to DIOS allowed the Japanese integrated steel manufacturers to continue their earlier private R&D activities [Kitagawa, 2000; Meijer, 2000; Fruehan, 2000; Anonymous, 1997a]. Earlier ideas gained from their private R&D activities and the needs of individual firms were included in the R&D programme. NKK proposed the basic layout of the DIOS process. NKK also hosted the pilot facility. NKK was eager to acquire know-how concerning plant engineering and the operation of the process [Kitagawa, 2000]. Currently NKK is the only one of the eight Japanese integrated steel manufacturers who is seriously pursuing further commercialisation of DIOS. In the words of the engineer who is leading the activities at NKK: *"The other Japanese steel firms know how important such tacit knowledge is in constructing and operating the facility. … DIOS will die as the people who have the knowledge hidden in their heads retire from NKK. We thus have to commercialise the technology as early as we can. ... Probably the other steel firms simply observe what NKK does and they may ask NKK to transfer the technology in the end" [Kitagawa, 2000]*.

The example of the co-operative DIOS R&D programme illustrates that the firm which was one of the proponents of the DIOS R&D programme is also the one who continued activities after the co-operative R&D activities had finished. Such firms appear to play a decisive role in the continued effect of the co-operative R&D programme in terms of accelerating its development.

The European integrated steel manufacturers British Steel, Hoogovens and Ilva knew each other through regular meetings of the ECSC's RTD programme. They had also co-operated in earlier projects that were supported by the ECSC. Experts see this set up with meetings and exchange of views as a positive aspect of the RTD programme. It promotes contacts with other firms because you know the people you may address. Steel firms apply for ECSC support typically in pre-competitive stages of a process development when it is attractive to share expertise and equipment and to learn [Meijer, 2000; Robson, 2000].

The requirement of contacts and exchange between the firms participating in the RTD programme make these firms decide to do without ECSC support when projects reach a more strategic stage of development. However, the RTD programme allows firms to meet other actors who have similar R&D interests and R&D experiences. There is a 'pool' of actors who can meet and initiate explorative projects.

It is also interesting to see the role of government in the HIsmelt micro-network. The Australian mining company who took the lead in developing the HIsmelt process had an agreement with the Australian government. CRA's right to develop the ore deposits was accompanied by the obligation to consider technologies that could lead to processing operations like the production of iron or steel. This obligation was subject to technical and economic viability tests [Burrow, 2000; Dry et al., 1999; Prideaux, 1996; Innes, 1995]. Whereas Innes (2001) indicates that CRA would have undertaken the activities towards exploring smelting reduction without this government obligation, it did govern CRA's thinking concerning appropriate technologies. In the case of Hoogovens' CCF process there was a similar sense of commitment, this time to the Dutch government (due to the voluntary agreement on industrial energy-efficiency improvement) [Meijer, 2000].

Apparently firms feel committed to agreements they make with government. Naturally firms will put their own interests first when establishing such agreements, but if they feel a certain commitment to and a positive relationship with government, they are likely to consider the agreements seriously. Such agreements and commitments are not easily thrown overboard.

Although the evidence from this case study is not very strong, we feel justified in making the following suggestions about how government can stimulate networks and co-operation and maintain relationships with firms:

- The effect of co-operative R&D programmes in terms of accelerating a technology's development depend strongly on actors' intentions to participate in such co-operative R&D programmes.
- If government stimulates network formation and knowledge exchange it is important that firms or other actors in the target group can really learn from each other's experiences.
- If one-to-one agreements are made with firms, specific topics can be anchored in a firm's (R&D) agenda. Without harming their business stakes, firms appear to take their relationships with government seriously.

### Government support for demonstration

In two micro-networks, government intended to give support in connection with the building of two demonstration facilities. In both micro-networks government's contribution was legitimised by the wish to improve the energy efficiency of iron production [Kavanagh and Obenchain, 2000; Meijer, 2000]. We describe briefly why neither of these plans was ever realised and comment on the importance of 'energy efficiency' as an argument for integrated steel firms to invest in these demonstration facilities.

In North America, there was talk of building a demonstration facility at one of Stelco' steel sites in Canada. Stelco was interested in a demonstration facility that could process the firm's waste oxides [Ritt, 1998b; Anonymous, 1996d]. The demonstration facility was to cost 160 million US$. The US Department of Energy, the Canadian government and Stelco were to contribute 33% each [Kavangah and Obenchain, 2000]. The US Department of Energy had to withdraw the warranted R&D support when the US Congress became Republican in 1994. As a result the whole demonstration facility was cancelled. Stelco could not find another firm willing to co-invest, nor was it willing to increase its own investment. None of the North American steel firms really felt the need to invest so much risk capital in a non-proven technology [Fruehan, 2000; Kavangah and Obenchain, 2000; Meijer, 2000; Thompson, 2000].

In the Netherlands since 1997 there has been talk of building a demonstration facility at the Hoogovens' steel site in Ijmuiden. From 1995 onwards, Hoogovens' intention was to realise such a demonstration facility. Hoogovens started looking for a partner to co-invest. First, Hoogovens tried to join in with the plan for a demonstration facility in North America after all they needed a partner who could deliver the smelting reduction vessel to complement their CCF pre-reduction unit. They failed. In 1997, the Dutch government announced an intensification of Dutch climate policy in the so-called the $CO_2$ Reduction Plan[25]. The large amount of financial support made Hoogovens apply for a demonstration facility in Ijmuiden [Meijer, 2000]. Hoogovens was awarded 30 million US$, about 25% of the total expenditure required. Hoogovens had a similar budget available. There was thus still a financial gap of roughly 60 million US$. There were serious contacts with the actors developing the HIsmelt process. Once again, finance turned out to be the bottleneck. No firm wanted to increase its expenditure [Meijer, 2000; Burrow, 2000]. In March 1999, it was formally announced that the development of the CCF process had come to a halt for reasons already discussed.

In both micro-networks government support for the demonstration facilities was legitimised by claims on an improved energy-efficiency [Fruehan, 2000; Meijer, 2000; Moors, 2000a]. The steel firms were primarily interested in reducing the cost of a ton of hot metal (whether using iron ores or waste oxides). Improvements in energy-efficiency alone would never have been a big enough incentive for Stelco and Hoogovens to invest in such a high-risk (and capital intensive) demonstration facility [Kavanagh and Obenchain, 2000; Meijer, 2000; Moors, 2000b].

Regarding the question of whether government can successfully contribute to the realisation of demonstration facilities we come to the following conclusions:

- The amount of government support can trigger a firm's interest in building a demonstration facility (even if the project is strategic).
- Government and steel firms' arguments for investing in a demonstration facility differed; governments interests in energy-efficiency was only part of the overall cost considerations of the steel firms. In spite of such differences, government involvement can be additional in building a demonstration facility.
- The empirical material shows that at this stage of technological development when firms are hesitant steering is an appealing, though highly complex task. On the one hand government support can be additional and - possibly - greatly accelerate a development. On the other hand there is a substantial budget of public money at stake. Firms were rather reluctant to commit themselves,

[25] The Dutch government set aside a major budget for concrete investment projects that would lead to the immediate reduction of $CO_2$ emissions. In spite of the fact the CCF process was not yet in at the stage of a commercial scale investment project that would lead to immediate $CO_2$ reductions government support was granted. In the contract with the Dutch government Hoogovens committed themselves to investment in a commercial facility *if* the demonstration facility was to operate satisfactorily and *if* the process was to be economically feasible [Meijer, 2000].

because large-scale investment decisions affect the daily business routine of steelmaking operations. Many factors are beyond government control and these may thwart the plans for demonstrating an innovative technology. In giving a firm and a specific technology a preferential treatment government should be well aware of the technical, economic and energetic consequences and opportunities.

## 6.5. Conclusion

Smelting reduction technology is widely acknowledged as an important innovative technology that can improve the energy efficiency of iron production. In this chapter we have evaluated the effect of government intervention on the development of smelting reduction technology. We investigated in detail the composition of and the changes in the networks developing this specific energy-efficient technology. We increased insight into actors' arguments for being involved in the development of this innovative technology and thus found out how government intervention affected actors' R&D decisions.

The network

Our network analysis has illustrated the various roles played by integrated steel manufacturers and mini-mill steel operators. Whereas several integrated steel manufacturers in industrialised countries were active in developing smelting reduction technology most of them lost interest. The innovative technology was 'locked out' by a continuous improvement of the existing ironmaking facilities. In addition the integrated steel manufacturers did not need to expand the existing ironmaking capacity. Mini-mill operators typically did not invest in the development of such core process high-risk technologies, but recently some mini-mill operators have shown interest in smelting reduction technology. Although application of smelting reduction technology in integrated mills has probably been postponed for at least ten years, application of smelting reduction in mini-mills may be a first niche application for proving the feasibility of smelting reduction technology. However if hot metal replaces processing of scrap, the production of steel in mini-mills will become more energy-intensive.

Government intervention

Various national governments and the European Coal and Steel Community played an active role in stimulating the development of smelting reduction technology. We estimate that 20 to 25% of the total expenditure needed for smelting reduction technology was supplied by various national governments or by the ECSC. The interesting questions are whether government support resulted in additional activities, whether it accelerated technological development and whether it might results in a lower consumption of energy for future production of iron.

We conclude that government R&D support enlarged the technology network. In five of the nine micro-networks, government R&D support definitely underpinned the performance of additional R&D activities. Three of these five micro-networks developed a smelting reduction process that is likely to be energy-efficient. We use the term 'likely' because the micro-networks are not yet ready to commercialise the technology. Two of these micro-networks have even shelved their efforts. Therefore, we must conclude that whereas government R&D support was additional, so far it has not accelerated technological development.

We have also seen that a commitment by government to support a demonstration facility can be a factor that persuades a firm to demonstrate a technology. Steering in this stage of a technology's development may be an appealing, though highly complex task. In giving a firm and a specific technology a preferential treatment government should carefully assess whether support may accelerate technological development (in the international technology network).

In addition to financial support, environmental regulations were not decisive in initiating or continuing R&D efforts. Reducing environmental emissions – and also improvements in energy efficiency – were only additional reasons for integrated steel firms to be interested. However, they provided researchers and engineers within a firm with an additional argument for continuing R&D.

All in all, the case study illustrates that integrated steel firms tend to constrain technological development so that it prefers certain – more incremental – directions. The existing capital stock was continuously improved which caused a decrease in the cost advantage of the innovative energy-efficient technology. This mechanism considerably limited the effect of government intervention and R&D support.

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# Chapter 7

# Technology networks and government intervention

## 7.1. Introduction

Governments consider the development of innovative energy-efficient technologies for industry an attractive option for reducing greenhouse gas emissions. The aim of the thesis is to gain insight into the process by which such technologies are developed. The underlying interest is to explore how government can stimulate their development. In Chapter 1, we argued that it is worth making a detour. Therefore we did not start by evaluating government intervention strategies, but we first wanted to obtain a better understanding of the role of actors and of the dynamics in the development of industrial process technologies. After the analyses of the four technology case studies, the case studies are compared and contrasted in order to explore possible ways in which government can stimulate the development of energy-efficient process technologies. In this chapter, we return to our research interest in government intervention.

In Section 7.2, we compare and contrast the insights gained from the four case studies with regard to six issues. In Section 7.3, we summarise what our research has contributed to technology studies and energy analysis. In Section 7.4, some policy-relevant conclusions are presented. We finish by giving some recommendations to enhance the effect of government intervention.

## 7.2. Comparing and contrasting technology case studies

### Introduction

Each of the four technology case studies tells its own story about the way in which a specific energy-efficient process technology developed. Table 1 gives an overview of the status of the technology network (in terms of the number of micro-networks) and the shortest summary of the four stories.

*Table 1: Summarising the four technology case studies.*

| **Case study** | **Sector** | **Number of micro-networks** | **Micro-networks active in 2000** | **Process of developing the energy-efficient process technology** |
|---|---|---|---|---|
| Shoe press technology | Paper | 1 | (2) [1] | Small network – continuing success<br>Only one persistent micro-network was needed for the successful development and innovation of shoe press technology, which marks a tremendous departure from the existing pressing configuration. Competing machine suppliers had to follow. |
| Impulse technology | Paper | 2 | 1 | Government R&D support allows the continuation of R&D<br>After more than 25 years, the future of impulse technology is still being debated. Although government R&D support led to continued R&D activity and acceleration of the development, the case study illustrates that government can become (too) dependent on research institutes. The history of impulse technology is a continuing story of stress being put on different (and changing) 'promises'. |
| Strip casting technology | Iron and steel | 11 | 6 [2]<br>of which: 3 industrial scale | Serious efforts at the edge of breakthrough<br>After more than hundred years when the idea of strip casting had been known, several micro-networks recognised and felt the economic need to pursue the development of this technology as the next step in steel casting. Three micro-networks are at the point of selling/building commercial-scale casters. |
| Smelting reduction technology | Iron and steel | 9 | 6<br>of which: 3 pilot scale | Double perspective<br>The development of smelting reduction technology has been undertaken by a variety of actors. Its application in integrated mills seems to be 'locked out' as a result of continuing improvements in existing capital assets. An opportunity is emerging for applying the technology in mini-mills. |
| Total number | | 23 | | |

[1] After Beloit introduced the shoe press to the market, two more micro-networks emerged. The micro-network which developed the shoe press is no longer in business. [2] Two of the eleven micro-networks merged into one micro-network.

Each of these four case studies had a specific character, although we used the same framework for analysing the four case studies. In this section, we generalise our findings; we suggest some plausible insights gained by comparing and contrasting the four case studies (see Section 1.5 and [Yin, 1989]).

We selected six issues for this comparison. The first three issues relate directly to the triangle of technological development which we used to arrive at the framework. We first consider the actors and networks that were involved in developing the technologies. Second, the artefacts are analysed. The third issue deals with the agenda; what guided actors in their R&D activities? The fourth issue is 'momentum', which is introduced to characterise the overall dynamics of a technology network. Two final issues deal with the possible ways in which governments can stimulate the development of energy-efficient technologies. The fifth issue concerns the effect of government R&D support. The final issue concerns the effect of alternative government intervention strategies. For each of the issues we make a summary of insights that are relevant for government intervention.

## Actors - Size and composition

In this section, we first look at the type of actors that make up the four technology networks. Second, we discuss what type of actors took the initiative in developing the innovative technologies. Third, we take a closer look at the changes in the size of technology networks. Fourth, we focus on the relations between actors within the micro-networks.

1. Types of actors: different patterns among manufacturing industries

Figure 1 gives an indication of the importance of various types of actors in the four technology networks.

Figure 1 illustrates the different roles of steel manufacturers and paper manufacturers in developing energy-efficient technology. The role of paper manufacturers in R&D was modest and in general quite passive. They waited for other actors to develop the technologies affecting the core of the paper-making process. Steel manufacturers (especially integrated steel manufacturers) played an active role in developing both strip casting technology and smelting reduction technology[1]. General R&D statistics also reflect this difference in the role of manufacturing firms in these two industrial sectors[2] (see also Table 2).

[1] Mini-mill steel firms do not invest in R&D themselves, just like the manufacturers in the paper industry they wait for others to develop process technologies. Both in the development of strip casting and smelting reduction technology, mini-mill steel-makers showed interest the moment the technology could be applied on a scale suitable for their mini-mills.

[2] These patterns of innovation are not static. Machine suppliers took the lead in the development and introduction of thin slab casting technology (1989). Steel manufacturers, both mini-mills and integrated steel manufacturers, simply buy thin slab casting technology. Steel experts discuss whether machine suppliers will increasingly take on the task of developing process technologies. Because machine builders are becoming larger and larger, it is easier for them to engage in high expenditure and develop innovative process technologies. Steel manufacturers are still rationalising their corporate R&D departments [Birat, 1999; Tacke, 1999].

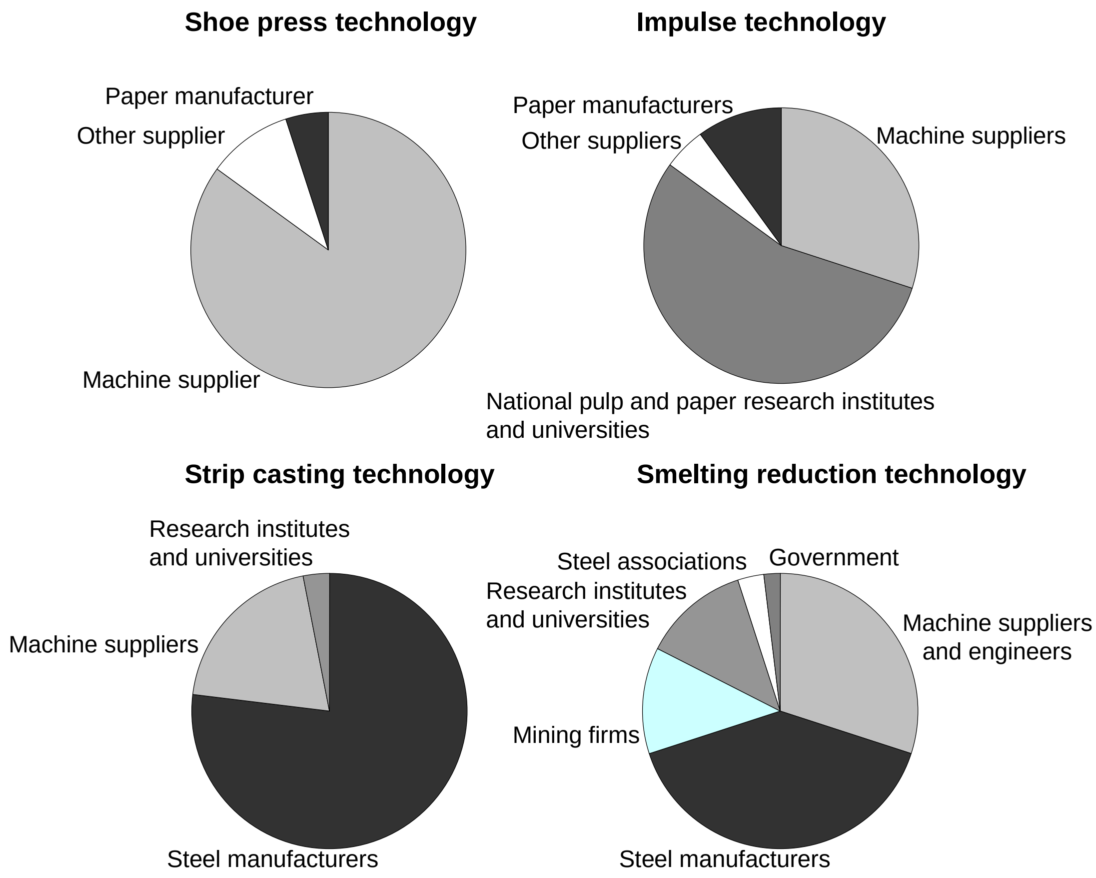


*Figure 1:* *Type of actors involved in the four technology networks. The role of each type of actor within a micro-network was evaluated. To compile these four diagrams, we divided a hundred points over the actors within each micro-network. The composition of the technology networks was derived by averaging the scores of the separate micro-networks.*

*Table 2:* *Direct R&D intensity and the indirect R&D intensity of the manufacturing industries considered.*

| **Sector** | **Direct R&D intensity**[1] | **Indirect R&D intensity**[1] |
|---|---|---|
| Pulp and paper industry | 0.31 | 0.57 |
| Iron and steel industry | 0.64 | 0.46 |

[1] Direct R&D intensity is the sector's R&D expenditure as part of the sector's total production value. The indirect R&D expenditure is the R&D expenditure embodied in intermediate inputs and capital goods which are supplied by other industrial sectors. The indirect R&D intensity is the imported R&D expenditure as part of the sector's total production value (input-output analysis). Data in table are a weighted average of the manufacturing sector in ten OECD countries [Hatzichronoglou, 1997].

If the compositions of the two paper technology networks are compared (see Figure 1), we see that in both case studies machine suppliers performed a crucial role by delivering innovative technology to the paper industry. One machine supplier dominated the development of shoe press technology. In the case study of impulse technology, national pulp and paper research institutes played an important part, but the research institutes typically left the innovation of the technology to the machine supplier.

There is a larger difference in the compositions of the two steel technology networks (see Figure 1). In developing strip casting technology, steel firms took the lead. Although they co-operated with machine suppliers or engineering firms, they controlled the R&D activities within the micro-networks. In the technology network of smelting reduction technology, the steel manufacturers played a less dominant role taking the lead in less than half of the nine micro-networks. Smelting of iron was clearly also interesting for mining firms because the process could add value to their raw materials. Furthermore, some engineering firms who had experience in building and selling smelting technology for other non-ferrous metals were also involved. The more heterogeneous composition of the smelting reduction technology network is explained by the specific operational processes involved in that technology.

2. Who took the initiative?

It was primarily firms who developed the energy-efficient technologies. In 19 of the 23 micro-networks, firms initiated R&D activities. In this regard, it is interesting to note that the firms were aware that the task they were engaging in was a substantial R&D effort, which would go on for many years and would require substantial investment.

Not only firms, also research institutes and universities played a role in the development of specific industrial technologies (see Figure 1). Institutes and universities were absent in the case of shoe press technology, and played only a modest role in developing strip casting technology. The largest contribution of universities and *public* research institutes occurred in the development of smelting reduction technology. In various micro-networks, firms looked for co-operation with research institutes in connection with some more fundamental issues.

In the case of impulse technology there was a major role for national pulp and paper research institutes[3]. However, these are *private* research institutes, not public ones. In the first place, they are supported by their member firms, which are national paper manufacturers and machine suppliers. Nevertheless, these major pulp and paper research institutes have close relations with universities. They are also experienced in mobilising additional external funds such as government R&D support.

[3] Such national pulp and paper research institutes are present in major pulp and paper producing countries like the US, Canada, Sweden and Finland. These countries also have a considerable university R&D infrastructure for pulp and paper.

However, we conclude that the *direct* contribution of knowledge by public research institutes and universities was only marginal in all four technology case studies[4].

3. Size of the technology networks

Figure 2 gives an overview of the changes in the size of the four technology networks over time.

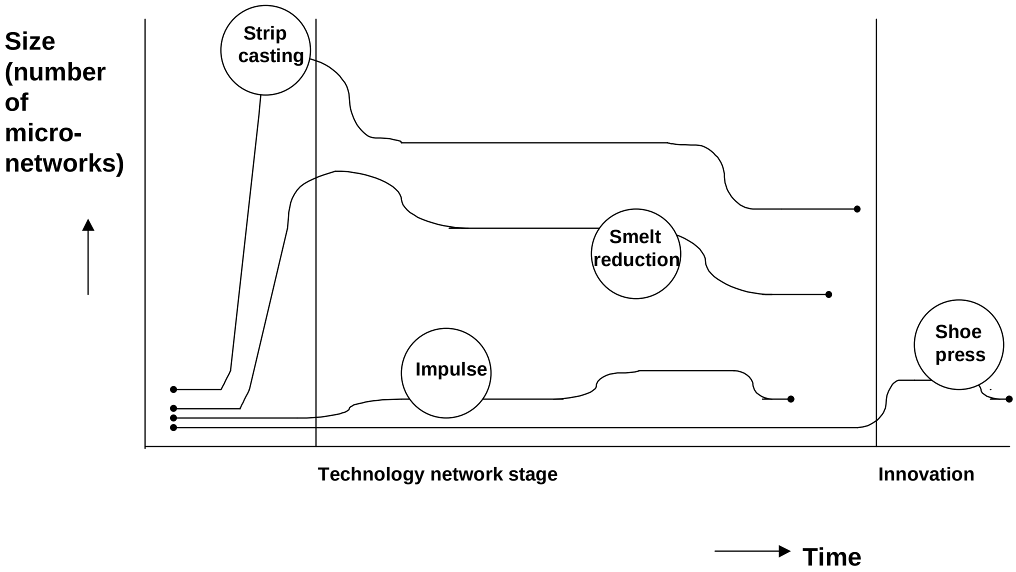


*Figure 2: The changes in the size of the technology networks over time (as measured by the number of micro-networks). Note that the size of the four technology networks is scaled between two moments: the emergence of the technology network and the moment of first commercial application (that has not yet been achieved in all technology case studies)[5].*

Figure 2 illustrates that the two steel technology networks are larger (as regards number of micro-networks) than the two paper technology networks. The absolute number of paper machine suppliers and major research institutes that can initiate such an R&D effort is small. It is at least smaller than the number of actors who have an adequate financial and knowledge base to develop innovative steel technologies. However, the total number of micro-networks – also in developing the steel

[4] It is very difficult to assess the importance of (earlier) more fundamental research in the development of the four energy-efficient process technologies. We know for instance that the development of strip casting technology was facilitated by knowledge about ceramic materials and process control. The development of shoe press technology evolved from a wider systematic approach and greater understanding of wet pressing.

[5] The micro-network developing the Corex smelting reduction process is not included in the smelting reduction technology network. Corex is commercially available. It is a first generation process that is less energy efficient than conventional ironmaking technology and that is not widely applicable.

technologies – is quite modest. It ranges from one to eleven micro-networks in the four technology networks (see Table 1). It is therefore possible to obtain an overview of the entire technology network.

The size of the technology networks changes over time (see Figure 2). Note that the two steel technologies show a similar development over time. A large number of relatively small-scale efforts were undertaken in the early days of the technology network. A substantial number of these efforts ceased their activities. Once a relatively stable technology network was in place, about one third to a quarter of the micro-networks ceased being active. This did not necessarily hamper the development. The case study of strip casting convincingly illustrates that although the size of the technology network decreased, the micro-networks that survived persistently moved in the direction of commercial-scale operation.

This leads to the question of whether there is a minimum size for a technology network if a technology is to have a reasonable chance of being commercialised. The case studies illustrate that the size of a technology network is not a straightforward indicator of the chance for innovation. On the one hand the shoe press case study shows that one micro-network can be sufficient. On the other hand the case study of smelting reduction technology shows that a large network is not necessarily sufficient for success. Nevertheless, we can say that smaller technology networks are more vulnerable. This is illustrated by the case of impulse technology. If the Swedish pulp and paper research institute had *not* managed to initiate a second micro-network in 1997 the development of impulse technology would already have come to an end.

4. Stable micro-networks

Table 3 gives a more detailed overview of the co-operation between actors *within* various micro-networks.

The second and third columns in Table 3 illustrate that it was only in a minority of the micro-networks that actors did not co-operate. Each of the four case studies illustrated that actors are generally well aware of their own limitations with regard to financial resources, specific knowledge, additional technologies, engineering experience, or specific R&D equipment. It is striking that in more than half of the micro-networks, co-operating actors came from different countries (see the fourth column Table 3). National boundaries do not seem to be a barrier to the establishment of co-operation. In six of the eleven steel multi-national micro-networks, co-operating actors even came from different continents. This did not occur in developing paper technologies.
Competitive steel manufacturers co-operated in both technology case studies. The fifth column in Table 3 indicates that this occurred in seven of the seventeen steel micro-networks. In three of these seven micro-networks, R&D was organised in a co-operative R&D project or programme in which a large number of steel

manufacturers combined their activities. Via financial R&D support, government supported all three micro-networks. In the other four micro-networks, steel firms co-operated in order to share costs or gain from each other's expertise and experience[6].

*Table 3: Co-operation within micro-networks.*

| **Case study** | **Total number of micro-networks** | **Co-operation in .. micro-networks** | **International co-operation in .. micro-networks** | **Co-operation between competing firms in .. micro-networks** | **Co-operation from the start of the micro-network or later?** |
|---|---|---|---|---|---|
| Shoe press technology | 1 | 1 | 0 | yes: 0<br>no: 1 | start: 0<br>later: 1 |
| Impulse technology | 2 | 2 | 2 | yes: 0<br>no: 2[1] | start: 1<br>later: 1 |
| Strip casting technology | 11 | 9 | 5 | yes: 3<br>no: 6 | start: 3<br>later: 6 |
| Smelting reduction technology | 9 | 8 | 6 | yes: 4<br>no: 4 | start: 5<br>later: 2<br>change: 1 |
| Total | 23 | 20 | 13 | yes: 7<br>no: 13 | start: 9<br>later: 10<br>change: 1 |

[1] Note that the national pulp and paper research institutes are supported by their members, which are all competing paper manufacturers.

The last column in Table 3 shows that in about half of the micro-networks, co-operation was initiated from the start of the micro-network. It is interesting to note that in nine of the ten micro-networks in which actors initiated co-operation 'halfway', this occurred at a moment when actors decided to take the step towards a larger scale facility. For this, they needed specific expertise or access to equipment or they simply wanted to share the cost of the more expensive facility. We have no indication that actors had problems in finding partners. If there were problems, this occurred typically at the stage when the technology had to be proven on a commercial scale[7].

[6] Usinor, a French integrated steel-maker, insisted on co-operative financing of large R&D projects like Myosotis (strip casting) and Jupiter (smelting reduction technology). In both cases, Usinor co-operated with Thyssen Stahl, a German integrated manufacturer [Birat, 2000; Lassat de Pressigny, 2000]. The Dutch integrated steel-maker Hoogovens co-operated with the UK British Steel and the Italian Ilva. These firms had also co-operated in earlier R&D activities [Robson, 2000; Meijer, 2000].

[7] We noticed such problems in four micro-networks. In the case study concerning impulse technology, one micro-network had problems in finding paper manufacturers willing to apply the technology on a commercial scale. None of the four attempts succeeded. In the case of smelting reduction technology, three micro-networks encountered problems in finding a co-investor in a near commercial scale facility. This caused delay in the materialisation of the technology within these micro-networks. In one of three micro-networks, the search for a partner took so long, that the competitive position of the technology deteriorated. In the end, this made the actors shelve the R&D effort.

The micro-networks turned out to be rather stable entities that continued R&D activities over considerable time periods. Although there was some knowledge exchange among various micro-networks in the technology network – especially in the case of smelting reduction technology, but also in the case of strip casting technology –, most R&D activities were organised in micro-networks. In three of the four technology case studies, we found evidence that personal contacts were important for initiating or continuing fruitful R&D activities within the micro-networks. The micro-networks are usually aware of the existence of other micro-networks. In three of the four case studies, micro-networks monitored other micro-networks' R&D activities, their (claims of) success and their failures.

Finally, it is remarkable that we encountered the same firms in both technology networks. In the two paper technology networks, we came across all four (by now only two) major machine suppliers. In both cases, Beloit led the developments. The role of Weyerhaeuser, a US board manufacturer in both case studies, is explained by the successful introduction of the shoe press and the involvement of the same persons. In seven of the eleven micro-networks developing strip casting technology we came across the same actors that were also active in developing smelting reduction technology. We conclude that firms differ substantially concerning their R&D strategy: some are substantially more innovative than others, at least in developing process technologies.

Summary

We now summarise the insights from this section that need to be taken into account when exploring possible ways in which government can stimulate the development of energy-efficient process technologies in Section 7.4:

- Firms initiated the development of the four industrial energy-efficient technologies. They also dominated the technology networks. The direct role of universities and public research institutes was marginal.
- The case studies illustrated the differences in the patterns of innovation in industrial sectors. Paper manufacturers tended to wait for others to develop and commercialise innovative process technologies, whereas integrated steel manufacturers or large stainless producers themselves took steps to invest in R&D.
- Whereas the technology networks that developed paper technologies were even smaller than the technology networks that developed steel technologies, the total number of micro-networks was modest. It is therefore possible to obtain an overview of the actors active in R&D.
- All technology networks were international. Even most micro-networks were international.
- Actors did not appear to have much difficulty in finding actors with whom to co-operate. Only in later stages of a technology's development were there problems in finding collaborators for co-investment in a (near) commercial (scale) facility.

## Artefacts - Time-frame and up-scaling

The number of years needed for developing specific technologies varies considerably (for overviews see e.g. [Jewkes et al., 1969; Van Duijn, 1983]). The time-frames for the development of the four energy-efficient technologies are contrasted in order to see what can explain the differences. We first see how the four innovative technologies match with the existing production process. Secondly, we make a distinction between the exploration stage and the technology network stage. Thirdly, we look at the steps in up-scaling the technology within the various micro-networks.

1. <u>Innovative technologies always have to match the existing production process</u>

The four innovative technologies are closely linked to the existing production process. The term 'existing production process' refers to the conventional sequence of process technologies used for manufacturing iron and steel or paper and broad. Table 4 explains to what extent the innovative technologies match with the existing production process.

*Table 4: The fit between the innovative technologies and the conventional production process for making iron and steel and paper and board.*

| **Case study** | **Reference production process** | **What does the technology do to the *existing* production process?** |
|---|---|---|
| Shoe press technology | <u>Paper or board machine</u>:<br>1 forming section<br>2 wet pressing section<br>3 drying section | Replaces part of the existing wet pressing section. |
| Impulse technology | | Replaces part of the existing wet pressing section. |
| Strip casting technology | <u>Integrated steel mill</u>:<br>1 ironmaking – ore, cokes, blast furnace<br>2 steelmaking – basic oxygen furnace<br>3 casting (conventional continuous casting)<br>4 rolling (hot strip mill)<br><u>Mini-mill</u>:<br>1 steelmaking – electric arc furnace<br>2 casting including rolling (thin slab casting) | Links casting and rolling into one process stage. Makes hot strip mill superfluous. |
| Smelting reduction technology | | Replaces blast furnaces. Makes ore agglomeration and coke ovens superfluous. |

The sequence of process technologies as indicated in the second column in Table 4, is found at every existing steel site and in every paper mill. In both industrial sectors, it is common practice for such major innovative technologies to be implemented first in *existing* production facilities before they are incorporated in greenfield steel plants or in new paper machines. The risk of trying out an unproven technology in an entirely new production facility is considered to be too high; manufacturers cannot afford the considerable capital expenditure and cannot afford to take the risk that the facility will not be operational from the moment of commissioning.

## 2. Distinguishing an exploration stage from a technology network stage

When we examined the time-frames for the development of the four technology case studies, we noticed that in all four cases we could distinguish between an exploration stage and a stage in which a technology network was established. This distinction is indicated in Table 5.

*Table 5: Time frames for the development of the energy-efficient process technologies.*

| **Case study** | **Duration of exploration stage [years]** | **Duration of technology network stage [years]** |
|---|---|---|
| Shoe press technology | about 15 | 13[1] |
| Impulse technology | about 10 | more than 20[2] |
| Strip casting technology | about 120 | about 20 |
| Smelting reduction technology | about 45 | 10[3]<br>more than 20[4] |

[1] The time that Beloit's competitors needed for developing the technology is not taken into account because they only started developing shoe press technology when the technology had been introduced to the market. [2] Not yet proven. Impulse technology is only operational in pilot paper machines. [3] It took ten years to introduce the first generation Corex process to the market. This first facility was on a moderate scale. It took five more years to prove commercial operation at double the scale of the first facility. [4] Not yet proven. None of the second generation processes is yet operational on a near-commercial scale.

At the exploration stage the principle or the idea of the innovative technology was already known. Actors may even have undertaken R&D activities to explore the possibilities of the technology. Actors may have been aware of others' actors also exploring the technology. However, a robust technology network had not yet emerged. The technology network stage takes off when the idea becomes entrenched: as R&D activities become anchored in R&D projects, the technology figures prominently on the actors' R&D agenda and remains a priority for a substantial number of years. It is not always easy to make the distinction between the two stages. In the case of shoe press technology, for instance, one can argue that the technology network seriously emerged only after the shoe press had been introduced.

When does this shift from the exploration stage to the technology network stage occur? What factors contribute to this change?
If we analyse the four technology case studies, we find a variety of elements that contributed to this shift. Table 6 gives an overview of these elements. It turned out that these elements can be grouped into four aggregate factors. Note that the factors listed in Table 6 do not explain why specific actors initiated or undertook R&D activities.

*Table 6: Which elements contributed to the shift from the exploration stage to the technology network stage in the four technology case studies?*

| **Case study** | **Factors** | **Elements from case study** |
|---|---|---|
| Shoe press technology | Economic need | Improving dryness in wet pressing permits an increased machine capacity / a reduced capital intensity. |
| | Technical need/match | The dryness at the exit of the wet pressing was to become a critical bottleneck for a further increase in machine capacity of board. |
| around 1970 | Progress in R&D | Basic studies (started around 1960) showed that the short time for pressing was a limiting factor. |
| around 1980 | Contingen-cies | Wet pressing was an important issue in Beloit's R&D agenda; freedom to look for entirely new ideas + management support. Beloit persistently initiated and continued R&D; they believed in a radically new press design whereas other machine suppliers did not. |
| Impulse technology | Economic need | Improving dryness in wet pressing permits an increased machine capacity / a reduced capital intensity. |
| 1980 – 1983 | Technical need/match | |
| | Progress in R&D | |
| | Contingen-cies | After 10 years the inventor succeeded in anchoring R&D at a pulp and paper research institute. He had shelved the effort twice before; no research capacity; did not suit machine supplier' main market. President pulp and paper research institute favoured the idea. Beloit was eager to see how they could further improve wet pressing performance after the success of the shoe press. Government R&D support. |
| Strip casting technology | Economic need | Linking casting and rolling leads to more compact process → cheaper steel. |
| 1980 – 1985 | Technical need/match | Conventional continuous casting was a first step in making the advantages of thinner casting tangible. When conventional continuous casting matured, attempts were made to find technologies that could further extend the advantages. Steel crises reinforced the need for more compact technologies. From the 1950s onwards both small-scale stainless steel production and small-scale mini-mill steel production had grown. |
| | R&D | Majority of R&D focused on conventional continuous casting. R&D in rapid solidification (60s and 70s) induced interest in strip casting. More knowledge of ceramic materials and process control. |
| | Contingen-cies | In the early 1980s, mutually reinforcing factors – amongst others Allegheny's claim of success (1984) – strengthened support/interest in strip casting technology. |
| Smelting reduction technology | Economic need | More compact process technologies → cheaper iron. |
| | Technical need/match | The need to replace obsolete conventional coke ovens early 21$^{st}$ century (huge capital expenditure). |
| 1975 – 1985 | Progress in R&D | For a long time coke oven/blast furnace dominated the R&D agenda (gradual up-scaling of capacity during 1950-60s). Growing experiences with scrap and coal in steel converters. |
| | Contingen-cies | Direct reduction technology did not turn out to be technically/economically feasible. Actors saw smelting reduction technology as the only serious challenge to the dominant conventional coke oven / blast furnace route for ironmaking. |

A first factor is that actors recognise the economic advantage of the innovative technology. This factor is critical. However, it is no guarantee that a robust technology network emerges. In the case of strip casting technology, the huge capital advantages were clear to Bessemer (1857). However, strip casting was too big a step for the steel industry to take at that moment in time. In the case of the shoe press, the principle and advantages were recognised, but the majority of the paper machine suppliers did not foresee an operational solution for extending press time. The decisive role of the economic advantage of the innovative technology cannot be evaluated without taking the other factors into account.

A second and very important factor is the technical need or match with the existing production process. The performance of the existing production process guides actors' R&D activities; innovative technologies may improve the competitive position of these industries, but the existing production process is generally the starting point in the search for innovative technologies. At a certain moment, specific pressing bottlenecks may occur which require an alternative solution; an innovative technology may be recognised as an interesting solution. Alternatively, changes in the manufacturing industry's production process or in the industry itself make the advantages of an innovative technology more visible.

A third factor that can affect the shift from the exploration stage to the technology network stage is progress in R&D. New insights and R&D results – possibly in related technical areas – may increase actors' confidence that an innovative idea will become an operational technology. Losing interest in other 'competing' innovative technologies or less R&D focus on the conventional technology may also contribute towards this shift. Only then does innovative technology become the centre of R&D attention.

Finally, in most cases contingencies played an important role in instigating R&D activities at a particular moment in time. Elements like for instance personal contacts, or alertness of a person in picking up a specific idea or suggesting that an 'old' idea should be revived may be crucial for getting things started and for showing other actors that the innovative technology is an interesting route to explore. It helps if the right people are at the right place at the right time and meet the right people.

The shift typically extends over a few years in which actors acknowledge that the innovative technology may be an interesting 'next-step-to-take' (see first column, Table 6). We use the term next-step-to-take to indicate that at a certain moment actors realise that an innovative technology is economically attractive and technologically feasible improvement. There is no single trigger that explains the shift to the technology network stage. A combination of factors and mutual reinforcement are needed for the technology network to emerge.

The four factors that may contribute towards this shift illustrate that merely evaluating the technology's technical or economic characteristics is not adequate to explain why actors initiate the development of a technology at a certain moment.

## 3. Up-scaling the technology

We go on to discuss the duration of the technology network stage. Table 5 indicates that the technology network stage takes at least ten and possibly more than 25 years. Note that the time that micro-networks need for developing a technology can be shorter than the time indicated in Table 5. Figure 3 gives a schematic presentation of the various steps in up-scaling the research equipment needed to develop the four energy-efficient process technologies.

Figure 3 is a simplification of reality. The process of developing the four innovative technologies was not as linear as the schematic steps shown in Figure 3. Nevertheless, all case studies illustrate that certain steps have to be taken to prove to the manufacturing industry that a technology is feasible. Although there can be differences in the actual size of equipment, we could distinguish regularities and similarities in the number of steps taken to enlarge the capacity of the R&D equipment and facilities.

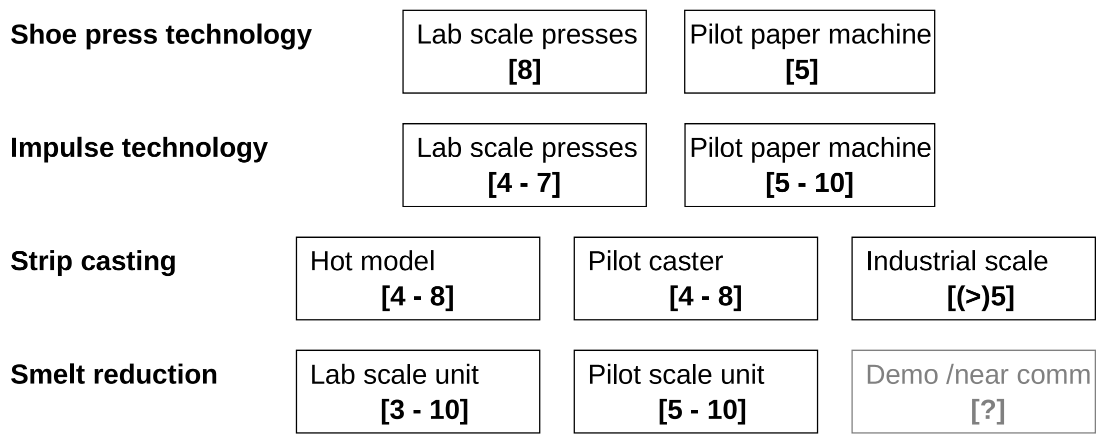


*Figure 3:* *The steps taken in up-scaling R&D equipment. Each rectangle symbolises a step. The numbers between the square brackets indicate the ranges in years during which R&D activities in the various micro-networks took place. The third step in developing smelting reduction technology has not yet been realised (apart from Corex). The capacity of the first commercial Corex facility (1989) was comparable to what is indicated here as demo / near commercial scale.*

In the cases of shoe press technology and strip casting technology, micro-networks brought the technology towards commercialisation in a relatively smooth and fast process. In the development of shoe press technology, two steps – lab scale facilities and implementing the press on a pilot paper machine – were taken before it was applied to a commercial paper machine. The search for a feasible design took about eight years. Five more years were needed to get a first shoe press installed. In the

development of strip casting technology, the three most advanced micro-networks all took three steps. Each step took roughly five to seven years. The equipment had to be built, the research had to be done, problems had to be solved, and the next step in developing the technology had to be prepared (organise financial resources and initiate co-operation if required).
All in all, the number of years that micro-networks were active is not particularly large in view of the various steps in up-scaling that have to be taken to prove the feasibility of the technology. The number of steps is an important determinant of the *minimum* pace at which an innovative process technology develops. The empirical material allows us to derive a rule of thumb for the minimum time; one needs to multiply the number of steps needed to up-scale the technology by five to seven years.

The four technology case studies also illustrate that the scale-up can be delayed by major unexpected difficulties, time-consuming efforts to mobilise research funds, problems in finding an actor in later stages of a technology's development, and uncertainties about a technology's performance in relation to the capital investment required. Sometimes actors simply intend to continue R&D on smaller scale equipment.

<u>Summary</u>

We summarise the insights we have gained concerning the rate at which technological development occurred:
- The actors involved in developing innovative process technologies aimed firtsly at implementing the technology in existing paper mills or steel sites.
- It took a while – decades to more than a hundred years – before the innovative technologies were supported by a robust technology network. The economic advantage of the technology was an important impetus. In addition, matching innovative process technologies with the existing production process played an important role. Progress in R&D activities and contingent elements that caused a specific actor to start R&D activities influenced the emergence of the technology networks. The innovative technology had to become recognised as the 'next-step-to-take'.
- The number of steps required for up-scaling a specific technology indicated a sort of minimum duration for introducing the technology to the market. Each step took five to seven years.
- Developing the core process technologies took time. For two or three up-scaling steps, a time period of 10 to 20 years was not exceptional.

### Agenda - Which promises orient technological development?

As discussed in Chapter 2, an agenda contains the shared ideas and guidelines that orient actors in their R&D activities [Van Lente, 1993]. In this section, we first point to the ‘promising’ performance characteristics of the four innovative energy-efficient technologies. We explain why precisely these promising performance characteristics were shared. Second, we describe how the promising performance characteristics changed as the technology materialised. Third, the arguments why certain micro-networks stopped their R&D activities are indicated. Finally, we analyse the importance of energy efficiency in the development of innovative process technologies.

## 1. Promises and constraints of the existing production process

Table 7 summarises the major promises of the four innovative energy-efficient technologies.

*Table 7: What the innovative process technologies promised?*

| Case study | Promise | Implications for production process | |
|---|---|---|---|
| Shoe press technology | Increased dryness → reducing cost per ton | Existing mills | Increased paper machine capacity |
| | | New mills | Reduced capital intensity (shorter drying section) |
| Impulse technology | Increased dryness → reducing cost per ton | Existing mills | Increased paper machine capacity |
| | | New mills | Reduced capital intensity (shorter drying section) |
| Strip casting technology | Compact casting technology → reducing cost per ton | Integrated steel mills | Reduced capital intensity |
| | | Mini-mills | Reduced capital intensity; access to new product market |
| Smelting reduction technology | Compact ironmaking technology → reducing cost per ton | Integrated steel mills | Reduced capital intensity |
| | | Mini-mills | Hot metal supply; access to new product market |

Table 7 shows that in both manufacturing industries, the promised reduction in costs per ton product was the dominant argument for investing in the technologies’ development. The experts consulted pointed out that the dominant business logic of the majority of steel- and paper-making firms explained the attention for cost reduction. The cost price determines whether firms can operate competitively. Manufacturers are forced to deliver their typical commodity products at the lowest cost. The market in which manufacturers operate is an important guideline that orient actors in their R&D

To act according the guideline of reducing costs, all actors were strongly constrained by the capital investment already made in the existing production process (see also discussion on Table 4). This constrained the direction in which innovative technologies in both manufacturing industries were to develop. All four innovative

technologies had the potential to strengthen the cost performance of the existing production process.
The paper machine, for instance, had not changed since paper-making became a continuous operation in the first half of the 19th century. The current production process still consists of the same three sections. Paper manufacturers have always tried to improve the production output of paper machines by increasing the width or speed of a paper machine. The capacity of both existing and new paper machines is maximised against the lowest cost. Both shoe press and impulse technology aimed to increase production capacity too.
In the steel industry the existing production processes greatly influenced actors in their choice of further technological development. Before the steel crisis during the 1970s, the dominant focus was to enlarge the capacity of the conventional process technologies like blast furnaces and basic oxygen furnaces. Since the steel crisis and the emergence of the mini-mill steel route, integrated steel manufacturers have become more interested in innovative technologies that physically shorten the existing production process. Both strip casting technology and smelting reduction technology aimed to reduce costs by making the conventional production process more compact.

In the former section on artefacts we used the term next-step-to-take to indicate that at a certain moment actors see an innovative technology as an improvement that is economically attractive and technologically feasible. It is almost paradoxical that whereas the innovative technology has to be recognised as the next-step-to-take – implying a certain continuity and incremental change –, the improvements in the dominant performance characteristic has to be large enough to justify the efforts needed to develop the technology. In all four innovative technologies a *stepwise* improvement in the overall performance of the existing production process was promised (at the firm level). The four innovative technologies involve major and complex R&D efforts; unless the potential advantages had been promising a stepwise improvement, it is very unlikely that any efforts would have been made. The risks involved would have been too high.

Thus, the desire to produce paper or steel at the lowest cost dominated the R&D agenda for innovative process technologies. Capital investments already made in the conventional production process strongly constrain the direction of technological development.

2. Is the promise of improved performance fulfilled?

When actors invest in R&D, one hopes that the performance of the technology is reconfirmed when it materialises within the micro-network. Table 8 gives an overview of how the perceived performance of the original promise changed over time.

*Table 8: Changes in promising performance characteristics over time.*

| | **Promise** | **Change?** | **Explanatory remarks** |
|---|---|---|---|
| Shoe press technology → commercially available | Dryness | Unchanged<br><br>First doubt, later acceptance | Board grades: note that strength properties also improved (1st application 1980).<br>Light-weight grades: only when conventional press technology limited increase production capacity was shoe press considered (1st application 1994). |
| Impulse technology → pilot machines | Dryness | Worsened | Original expectations were not met. Researchers started to stress 'other' performance characteristics. |
| Strip casting technology → near commercial scale | Compact process | Unchanged | - |
| Smelting reduction technology → pilot scale | Compact process | Worsened | Existing conventional capital assets were continuously improved + no need for additional iron-making capacity. |

Note that we can only measure the perceived performance of an innovative technology through the eyes of the actors' involved in a technology's development. Table 8 therefore reflects the actors' perception of the promising performance characteristics as articulated in written materials and expert consultation[8].

The introduction of the shoe press to grades other than board grades clearly illustrates that performance characteristics alone do not explain the investment behaviour of light-weight paper manufacturers. Since the shoe press was applied for the first time in board grades (1980), machine suppliers claimed an increase in dryness for light-weight grades too. Light-weight paper manufacturers feared that important product characteristics would be lost. It took 14 years to overcome the inertia of the light-weight paper manufacturers. By then, however, the press impulse of the conventional wet pressing section had become a major bottleneck preventing a further increase in machine speed. Shoe press technology was a suitable option to escape this dilemma.

Table 8 leads us to conclude that the two most smoothly developed technologies, shoe press technology and strip casting technology, lived up the expectations with

[8] Written literature or articles did not permit to obtain a quantitative overview of the changes that occurred over time in specific performance characteristics. Although there are generally a large number of technical articles covering specific, basic technical details, very few articles give a detailed account of the improved cost performance or the other improvements. Most statements about the performance of an innovative technology are found in trade journals. Such articles typically cover the operation of a technology and its greatest advantages in more general wording. Uncertainties can be substantial especially with regard to data about cost performance. Data found were based on small-scale equipment. Uncertainties arise in extrapolating results to commercial scale facilities. Often (cost) performance data were published in order to interest potential customers, to find a potential partner in R&D, or to interest external financiers in the research. We found most data on performance characteristics in micro-networks that were dependent on external support or in micro-networks that were trying to get other actors interested.

least uncertainty and discussion. These technologies raised the fewest doubts regarding the promising performance characteristics.

3. Stopping R&D activities?

Not all micro-networks continued R&D activities. Table 9 gives an overview of the arguments that were given for ceasing R&D activities.

*Table 9: Arguments for stopping R&D activities in micro-networks. For some micro-networks more than one argument is given, because specific actors within that micro-networks may have had different arguments.*

| | **Total number of micro-networks** | **Number of micro-networks that stopped** | **Bankruptcy / Merger / Sellig-off divisions** | **Research task fulfilled / aim gaining competence** | **Lack of performance perspective** |
|---|---|---|---|---|---|
| Shoe press technology | 1 | 1 | I | - | - |
| Impulse technology[1] | 2 | 1 | I | I | - |
| Strip casting technology | 11 | 4 | II | I | II |
| Smelting reduction technology | 9 | 3 | - | II | III |

[1] Note that a lack of performance perspective was the reason why two major machine suppliers did not initiate R&D relating to impulse technology.

The fourth column in Table 9 shows that in some micro-networks strategic business issues led to the cessation of R&D activities. In some other micro-networks, R&D activities were terminated in spite of successful R&D; the actors (not only research institutes but also firms) did not aim at commercialising the technology (fifth column).

The 6$^{th}$ column in Table 9 shows that in some micro-networks, R&D activities were stopped because the technology lacked performance perspective. There may have been more specific reasons for this. Expectations about the technology's performance might not have been met. However very often the lack of performance perspective was affected by for instance improved performance of the conventional technology, by the fact that the R&D activities may have taken too long already or that the capital investment required for making the next step may have been too high. There may have been problems in finding co-investors, there may not have been a need for the technology at that particular moment in time, actors may have decided to wait for the results of more advanced micro-networks, or actors may have become involved in other major capital expenditure.

Once micro-networks started R&D activities in the technology network stage major technical difficulties were never a decisive argument for ending R&D activities (in stead they were used as an argument for continuing R&D). Many factors that are not directly related to the innovative technology but to the context in which the technology was being developed thwarted the technology's development in specific micro-networks.

## 4. Is energy efficiency a promising performance characteristic?

Since our research interest is in energy efficiency, an important question is whether energy efficiency was a promising performance characteristic. How susceptible were the actors to energy efficiency as a motive for developing innovative technologies?
We conclude that improving energy efficiency was not a major argument in the development of any of the four industrial process technologies. Reduced energy costs was not the main argument that persuaded actors to invest in R&D. Only in the case of smelting reduction technology was reducing coal consumption a design criterion. However, even in this case study, savings on energy costs did not lead to the development of smelting reduction technology in the first place. The case of the shoe press provides empirical evidence that improved energy efficiency was not decisive in implementing the technology either. The four case studies suggest that innovative technologies that affect the core of the production process may bring about improvements in energy efficiency, but these are little more than positive side-effects.

Actors involved in developing the innovative technologies used the 'promise' of energy efficiency as an argument for mobilising external (government) support. This happened in all four case studies. This was clearest in the case of impulse technology. The national pulp and paper research institutes developing impulse technology were more dependent on external R&D support, and, as elsewhere, their R&D proposals tended to match government priorities for granting R&D support. The multiple advantages of the innovative technologies allowed actors to stress a range of promising performance characteristics, depending on the actor, supporter or customer whom they approached.

## Summary

To conclude this section on promising performance characteristics we summarise our insights that are relevant for government intervention.

- The market in which manufacturers operate is an important guideline that orient actors in their R&D. The majority of the manufacturers is forced to deliver their typical commodity products at the lowest cost. This dominated the R&D agenda in the development of industrial process technologies.
- The capital investments in the conventional production processes strongly constrained the direction of technological development; existing manufacturing production processes led to regularity in the technological development.

- Once micro-networks had started R&D activities in the technology network stage, major technical difficulties were never a decisive argument for terminating R&D activities.
- In the majority of micro-networks, a variety of reasons not connected to the (pure performance) innovative technology but to the context in which the technology was being thwarted the technology's development and led to the cessation of R&D activities.
- In none of the four case studies was energy efficiency a main argument for actors to develop the technology. The 'promise' of energy efficiency was however actively used to mobilise external (government) R&D support.

### Dynamics - The momentum of technology networks

So far we have discussed actors, artefact and agendas, and we have seen some of the saw dynamics that operate. How then can we characterise the overall dynamics? Here it is useful to introduce the concept of *momentum*.

The concept of 'momentum' is well known in technology studies. Hughes (1983) used it in his study of the electricity system, a large technical system (see also Chapter 2). A technical system consists of different technical and socio-organisational components. Hughes claimed that when such a system grows and consolidates the total 'mass' of technical and socio-organisational components has a direction and a rate of growth, suggesting velocity. The whole system expands at a certain pace and thus has a 'momentum'. A high level of momentum causes observers *to assume that a technical system develops autonomously* [Hughes, 1983].

We use the concept of momentum as a characteristic of the technology network. It is a characteristic of the constellation of actors rather than an intrinsic characteristic of the innovative technology. A technology network has a large momentum when it causes observers – analysts like us – *to assume* that the technology is materialising autonomously. This does not mean that the technology develops autonomously; it reflects that the actors involved invest steadily and regularly in the development of the technology.

A technology network with a large momentum is less vulnerable to changes in parts of the technology network or to obstacles that the actors may bring along. In other words: a technology network has a large momentum if the socio-technical elements that make up the technology are continuously and increasingly aligned [Callon, 1987].

Differences in momentum could be detected in the four technology networks (see Figure 4).

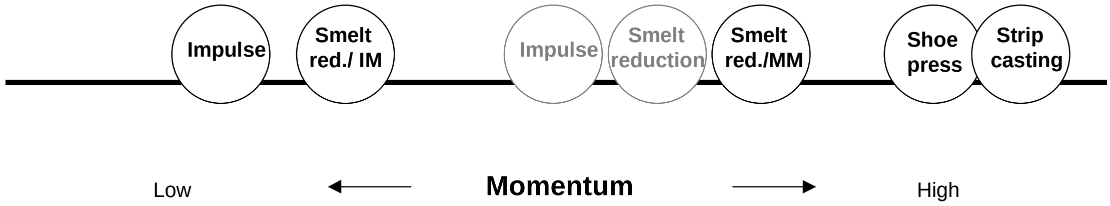


*Figure 4:* *The four technology networks ranked according to their momentum. In the case of smelting reduction technology and impulse technology, momentum decreased. The grey symbols indicate these technologies' former momentum. Note that the application of smelting reduction technology bifurcated. Integrated steel-makers lost interest. Application in mini-mills is a likely next step in the commercialisation of smelting reduction technology.*

We describe the momentum of each of the four technology case studies and explain what empirical evidence is used to indicate a technology network's momentum.

*Shoe press technology*

Although the technology network of shoe press technology was small (until the moment of innovation) it had a substantial momentum from the beginning. In spite of the various setbacks and the difficulties in achieving an engineering solution, R&D activities were continued with great dedication. The people at Beloit continued, although they knew that developing a shoe press was a tremendous engineering step to take. The technology network of shoe press technology gained further momentum from the moment when the first shoe press was applied commercially (1980). By then a larger technology network emerged; the success of the shoe press in improving the performance of board machines made all major competing machine suppliers (and fabric suppliers) jump on the bandwagon and develop a shoe press too. Beloit's competitors felt they could do nothing but follow, which reinforced the further materialisation of the technology.

*Impulse technology*

The momentum of the technology network of impulse technology has never been high and it decreased over time. A few major pulp and paper research institutes first initiated R&D activities (financially supported by government). Beloit, the machine supplier who had recently successfully introduced the shoe press, was also interested. The technology network grew. There was however a continuous stream of criticism. When a number of attempts to commercialise the technology failed, interest at Beloit waned; R&D activities continued, but with a lower priority. Other major machine suppliers were not interested. The technology network gradually lost momentum. Efforts to commercialise the technology failed more than once. In 2000, there was only one micro-network left which was lead by a major pulp and paper research institute. A major machine supplier was involved in the background, but this firm has more innovative technologies in its portfolio. Impulse technology's future is uncertain. Its momentum is rather low.

*Strip casting technology*

The technology network of strip casting technology has had a large momentum since the technology was widely regarded as an appealing next-step-to-take (Table 6). A large and robust technology network emerged and continued its R&D activities (even after thin slab casting had been commercialised (1989)). Although some micro-networks lost interest, momentum was maintained: integrated steel manufacturers (with a stainless steel division) persistently moved towards industrial scale casters.

*Smelting reduction technology*

The technology network of smelting reduction emerged only gradually (1975-1990), although its momentum was considerable. A large number of steel and engineering firms recognised smelting reduction technology as an interesting alternative ironmaking process due to the threat that obsolete coke ovens might have to be replaced at great expense. The technology network was quite heterogeneous. As time went on most integrated steel manufacturers lost interest. This was due to the extension of the lifetime of existing iron production facilities. In addition, the productivity of these facilities had gradually improved. Integrated steel manufacturers no longer needed to expand iron-making capacity. The development and commercialisation of an unproved technology became less important and the technology network lost momentum, at least as far as integrated steel manufacturers are concerned. Mini-mill steel-makers (or mining firms) might well be the first to exploit the promising advantages of smelting reduction technology.

To conclude, a technology network preserves its momentum only if actors continue their R&D activities and persistently bring the technology towards commercialisation. The momentum of a technology network reflects the *confidence* of actors in the development of that particular technology[9]. Actors must not lose confidence in the future prospects for the innovative technology, so that the technology remains the next-step-to-take.

In the former section on the agenda, we concluded that the two most smoothly developed technologies, shoe press technology and strip casting technology, lived up the expectations with least uncertainty and discussion. It is crucial for the maintenance of momentum that the actors involved in the various micro-networks are re-assured about their expectations; the *perceived* promising performance characteristics have to be confirmed or reconfirmed.

The performance characteristics have to be evaluated in its specific context. Actors decide upon continuing R&D against the backdrop of R&D activities within the entire technology network; against the backdrop of continuous technological

[9] It is important to note that often only a rather restricted number of competing innovative technologies are recognised in industrial sectors like paper and steel. Only a limited number of technologies are on the R&D agenda as a 'next-step-to-take'.

improvements to the conventional process technologies and of the development of competing innovative technologies; and against the backdrop of eventual trends and changes in the specific manufacturing industry – and possibly even in the firm itself -–. The materialisation of the technology, R&D results, claims of success (for instance by other micro-networks), difficulties (such as delamination), and failures in commercialising the technology all affect actors' confidence in the future prospects of the technology. Therefore, the momentum of a technology network may be affected[10].

We were able to rank the four technology networks with regard to their momentum. This implies that we were able to 'measure' momentum. How can an analyst assess the momentum of a technology network at a certain moment in time? We can think of two possible strategies.

The first is simply to ask experts involved in the development of the specific technology. Experts use the concept of momentum themselves to indicate their expectations about the technology's future breakthrough and performance. So, we can ask experts to assess the technology network's momentum and try to understand their reply.

A second strategy is to get answers to the following questions: Are R&D activities continued (in spite of improvements in conventional process technologies an competing innovative technologies)? Do actors continue to see the innovative technology as the obvious next-step-to be developed? Do actors continue to express confidence in the performance of an innovative technology (or are issues being debated)? Is the innovative technology being materialised within that technology network (regular steps in up-scaling)? Affirmative answers mean that the momentum of the technology network is being maintained. Such pieces of empirical evidence should be evaluated together in order to assess the momentum of a specific technology network.

## Government intervention - How effective was R&D support?

Government R&D support (subsidies) is the most widely adopted policy instrument for stimulating technological development. It is also the common means in stimulating the development of industrial energy-efficient technologies. In this section, we start with an overview of the role of government R&D support in the total R&D expenditure. The disadvantage of R&D expenditure data is that they say

[10] Hughes (1983) focused on expanding systems whereas we are interested in mature manufacturing industries. This is an important difference. In Hughes' studies, during the growth of a system some components are under-developed. Reverse salients occur. These are translated into critical problems that have to be solved in order to continue the growth of the system. We use momentum to characterise the technology network within a mature system: the innovative technology may further optimise the conventional production system. Development of innovative technologies occurs within the confines of the conventional production process and, generally, within a set of business and R&D linkages among actors who have an established reputation for developing or delivering process technologies.

little about what has been achieved; Did government R&D support contribute to developing the energy-efficient technologies? Before answering this question, we summarise governments' arguments for supporting technological development. We then discuss the effect of government R&D support. We also analyse how the effect of R&D support is related to the momentum of the four technology networks.

## 1. R&D expenditure

Table 10 gives an overview of the total R&D expenditure and government R&D support in developing the four energy-efficient technologies. It shows a difference in the total R&D expenditure for developing iron and steel technologies and paper technologies. The difference between the two is at least one order of magnitude[11].
In two case studies, impulse technology and smelting reduction technology, government R&D support has been substantial (more than a quarter of the total expenditure). In the other two case studies, the share is marginal (though not in absolute terms).

*Table 10: R&D expenditure and government R&D support.*

| **Case study** | **Number of micro-networks** | **Total R&D expenditure [M US$]** | **Government R&D support [M US$]** | **Government R&D support [%]** |
|---|---|---|---|---|
| Shoe press technology | 1 | 5 | - | - |
| Impulse technology | 2 | 35 – 40 | 15 | 40 – 45 |
| Strip casting technology[1] | 11 | 500 – 700 | 40 | 5 – 10 |
| Smelting reduction technology[1] | 9 | 600 – 700 | 165 | 25 – 30 |

[1] Government R&D support includes support from the Research Technology and Demonstration (RTD) programme of the European Coal and Steel Community (ECSC). The budget for the ECSC's RTD programme is gathered by a levy on the steel price.

## 2. Arguments for stimulating R&D

Table 11 gives an overview of the prevailing arguments that were given, for instance in policy documents or papers, by the various governments for legitimising government R&D support.

Table 11 makes it clear that most R&D support can be referred to as specific R&D support; government had certain intentions in *directing* technological development in a desired direction. Financial R&D support from the European Coal and Steel Community (ECSC) is the exception. We did not find any indications that generic

[11] There can be a considerable difference in the expenditure of particular micro-networks. In the case of strip casting technology, the three most advanced micro-networks spent about 65% to 75% of the total budget. The expenditure for developing an innovative paper technology is slightly flawed. Machine suppliers usually implement an innovative technology on their existing pilot paper machines. Building an entirely new pilot paper machine costs about 30 to 40 million US$.

government R&D support (e.g. generic tax subsidies on R&D personnel) directed R&D towards improving energy efficiency[12].

*Table 11: Governments' arguments for supporting the development of the four technology case studies.*

| **Case study** | **Country** | **Generic or specific?** | **Government argument** |
|---|---|---|---|
| Shoe press technology | US | S | - energy efficiency<br>- competitiveness industry<br>*Support never realised* |
| Impulse technology | US + Canada | S | - energy efficiency<br>- high-risk technology<br>- competitiveness |
| | Sweden | S | - energy efficiency<br>- high-risk technology<br>- competitiveness industry |
| Strip casting technology[1] | US | S | - energy efficiency<br>- competitiveness industry |
| | Canada | n.a. | |
| | ECSC | G | - R&D |
| Smelting reduction technology[1] | Japan | S | - clean coal |
| | US | | - energy efficiency |
| | Australia | S | - value added economic activity / employment<br>- exploitation of state-owned coal reserves |
| | ECSC | G | - R&D |
| | Netherlands | S | - $CO_2$ emission reduction<br>*Support never realised* |

[1] Note that ECSC support is included.

In all four technology case studies, industrial energy efficiency and related matters like reducing greenhouse gas emissions were reasons for government to grant R&D support. When discussing the promising performance characteristics of the four technologies, we already pointed out that energy efficiency was not an important argument for firms to develop the technologies. This does not necessarily mean that government R&D support was ineffective. However, there are risks that may undermine the effect of R&D support when actors and governments have different reasons for being interested in a technology. This discussion is continued in the following section.

[12] This does not downplay the other effects of generic R&D support. There are a number of econometric studies that indicate that generic R&D support results in additional R&D spending by firms (see e.g. [Donselaar and Knoester, 1999; Guellec and van Pottelsberghe, 2000]).

## 3. Effect of government intervention?

As indicated in Chapter 2, we distinguish three important terms when evaluating the effect of government R&D support:

- Additionality - R&D support is additional if actors would not have started or continued R&D activities without government R&D support. The additionality does not say anything about the continued effect of R&D support. Nor does it say anything about the importance of the supported R&D activities in developing the technology within a specific micro-network.
- Acceleration - R&D support accelerated technological development if it led to an accelerated materialisation of the technology *in the entire technology network*.
- Effectiveness - R&D support is effective if it leads to improved industrial energy efficiency. This is achieved only if in the end the technology is implemented and the firm-specific specific energy consumption is reduced.

Table 12 gives an assessment of the effect of government R&D support in developing the four energy-efficient technologies.

*Table 12: Effect of government R&D support: additionality, acceleration and effectiveness.*

| **Case study**<br>**Total number of micro-networks (=# of MN)** | | **R&D support in # of MN** | **Effect of R&D support** | | |
|---|---|---|---|---|---|
| | | | **Addi-tionaliy in # of MN** | **Acce-leration** | **Effectiveness** |
| Shoe press technology | 1 | - | - | - | Shoe press reduces steam consumption in drying section. Amount of energy efficiency improvement is machine specific. |
| Impulse technology | 2 | 2 | 2 | Yes | Whether an improved energy efficiency will result is uncertain (and debated). |
| Strip casting technology[1] | 11 | 6 | 3 | No | Results in improved energy efficiency. Is not likely to replace entire casting + rolling stages in integrated steel mills. |
| Smelting reduction technology[1] | 9 | 9 | 5<br>all process<br>3<br>energy-efficient process | No<br>so far<br><br>(did enlarge network) | Some processes are likely to be more energy-efficient than blast furnace *plus* coke ovens + agglomeration. If implemented in mini-mill (and *replacing* scrap), specific energy consumption will increase. |

[1] Note that ECSC support is included.

We also discuss the effect of government R&D support case by case.

*Shoe press technology*

In the development of shoe press technology, the machine supplier's attempt to acquire US government support for covering the risk of innovation was never realised. Both additionality and acceleration would have been minimal, since the machine supplier was eager to introduce the shoe press. The momentum was large.

*Impulse technology*

The R&D support by various national governments accelerated the development of impulse technology; the emergence of the technology network and the materialisation of the technology would not have reached the stage it is at today without government R&D support.

Why did government R&D support accelerate the development of impulse technology? Government support was granted primarily to the major pulp and paper research institutes, which are more often depending on external support for initiating and continuing R&D activities. The close relationships between the major pulp and paper research institutes and machine suppliers and the support of R&D activities by the institutes member companies were indicated to government that impulse technology was an appealing innovative technology. The relations and co-operation between the actors within the micro-networks were such that actors could benefit from each others' capacities and research facilities. The technology network did not have a very large momentum. This meant that government could support additional R&D activities.

In spite of all this, the case study of impulse technology illustrates one of the major risks that a government runs in supporting technological development: financial support may become the driving force in the R&D efforts. The researchers continued to attract government financial support by claiming improved energy efficiency. Government was patient in granting support[13].

Finally, whether R&D support was really effective – in terms of leading to improved energy efficiency – remains to be seen. The commercial feasibility of the current design is under debate.

*Strip casting technology*

The three micro-networks which are ahead in developing strip casting technology received no government R&D support (or it was only of a marginal nature). One of these three micro-networks did receive ECSC support during the early stages. However, this support was not additional. The contribution of government R&D support to a micro-network's total expenditure - % budget - and the additionality of

[13] Orloff (2000), who was the leading impulse technology researcher at the US pulp and paper research institute, wondered whether the research institute's R&D activities should have continued for such a long time. The institute's major lesson is that a thorough economic assessment has to be made at an earlier stage of R&D activities. Experts' opinions about the legitimate role of government R&D support in developing impulse technology differ. Some experts say that it was a waste of tax payers' money to support people who perform research simply because they have the funds available [MacGregor, 2000; Wahren, 2001; Woo, 2001]. Others are more temperate in their judgement on the effect of government R&D support [Boström, 2001].

government R&D support was largest in micro-networks that were *not* operating at the frontier of the technology's development. The effect of government R&D support in stimulating the development of strip casting technology has been minimal, because the technology network had its own strong momentum.

*Smelting reduction technology*
Government R&D support enlarged the technology network of smelting reduction technology. The US and Japanese national government and the ECSC support had an additional effect in three micro-networks that invested in a smelting reduction process that was likely to be energy-efficient. Roughly 90% of the government R&D expenditure indicated in Table 10 was spent on these three micro-networks. At this moment, only one of these three micro-networks – or actually one Japanese steel firm that participated in the formerly co-operative micro-network and has always been eager to develop the technology – is still active. Government R&D support did not accelerate the technology development so far[14].

These descriptions illustrate that although government R&D support has been a very popular policy instrument for stimulating the development of energy-efficient technologies, it is also a rather weak instrument. Government relies on the actors – their intentions, their plans, their embeddedness in a network of actors, their own private R&D investments, their strategic business decisions and their efficiency – to do something valuable with the financial R&D support.

Figure 5 summarises these descriptions on the effect of government R&D support. There is a relation between the momentum of a technology network (see Figure 4) and the effect of R&D support; the four technology case studies are located on the curve.

The curve helps to explain the effect of R&D support. The momentum of the technology networks engaged in developing strip casting technology and shoe press technology was high; R&D support did not have an additional effect. In such circumstances, it is difficult to intervene effectively since the is a high risk that government is not abreast of events or that R&D support is not additional. The momentum of the technology networks engaged in developing smelting reduction technology and impulse technology was lower; government R&D support led to additional R&D activities and enlarged the technology networks.

[14] We write 'so far' because one of the firms of the Japanese micro-network is still active. Their R&D activities have to be compared with another micro-network that achieved a similar degree of materialisation, although without government R&D support. The future plans of both micro-networks are still uncertain.

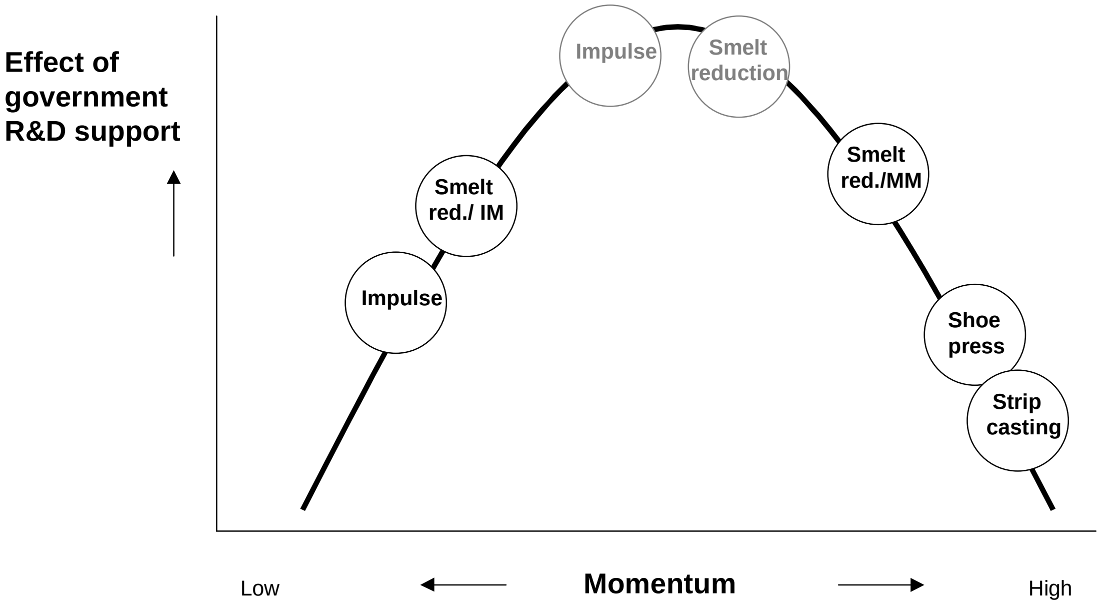


*Figure 5: The effect of government R&D support as a function of momentum. The four technology networks are located on the curve. In case of smelting reduction technology and impulse technology momentum decreased (see also Figure 4). The grey symbols indicate these technologies' former momentum. Note that the application of smelting reduction technology bifurcated.*

<u>Summary</u>

We therefore come to the following conclusions about the effect of government R&D support on the development of industrial process technologies:

- Government R&D support did accelerate the development of specific energy-efficient technologies.
- If technology networks had a large momentum, it was difficult for government to stimulate technological development effectively. Additionality is low; actors themselves are eager. The is also a risk associated with R&D support to the technology networks that have a low momentum. It was illustrated that financial support became the driving force in the R&D efforts. It remained uncertain if in the end the technology was technically or economically viable.
- Additionality of government R&D support was higher if firms were less inclined to develop and commercialise the technology.
- Actors were skilful in addressing a government's specific interest for developing an innovative technology.
- Government did not play a role in the exploration stage of the four technology case studies. Most often government became involved after the technology network stage had 'taken off'. However, in some cases government contributed to the emergence of technology networks.

## Government intervention - Alternative strategies

The notion that technological development is the result of interaction between actors rather than a linear sequence from science to market opens the way for alternative intervention strategies. These can take the form of (technology forcing) standards, voluntary agreements on technological development, facilitating and networking initiatives, organising co-operation, supply or transfer of information and knowledge, etc. (see also Section 2.3. and 2.4 in Chapter 2).

In the empirical case studies we did not see many of such alternative government strategies (see Table 13). In principle, the effect of such strategies can be analysed in the same way as the effect of R&D support – i.e. according to their additionality, acceleration and effectiveness –. However, the empirical material is too scarce and our comments must remain tentative.

*Table 13: Other government intervention strategies.*

| Case study | Government intervention strategies | |
|---|---|---|
| Shoe press technology | - | - |
| Impulse technology | Co-operation | - International Energy Agency (IEA): Implementing Agreement Pulp & Paper / Annex on impulse technology. |
| Strip casting technology | Co-operation | - ECSC RTD programme:<br>- formation of a working group on casting (around 1985)<br>- network of meetings<br>- two co-operative multi-partner *carbon* steel projects – 40 to 50% R&D support. |
| | Co-operation | - Co-operative R&D (Canada): Bessemer Consortium – 50% government R&D support. |
| | Co-operation | - Co-operative R&D (US): recent CMU project – 70% government R&D support. |
| Smelting reduction technology | Co-operation | - ECSC RTD programme:<br>- network of meetings |
| | Co-operation | - Steel Initiative / co-operative R&D programme (US / DSM): public-private effort to formulate priority areas for R&D and to select and support promising co-operative R&D programmes – 75% government R&D support. |
| | Co-operation | - Co-operative R&D programme (Japan / DIOS): opportunity for building a demonstration facility – 67% government R&D support. |
| | Regulation | - Environmental regulation in various industrialised countries |
| | Agreement<br>Agreement | - Voluntary agreement 2000 (CCF / the Netherlands)<br>- Technology agreement (Hismelt / Australia) |

1. <u>Regulation</u>

It was only in the development of smelting reduction technology that regulation played a role. It did not affect energy use, but it affected environmental emissions in the conventional iron-making process. The threat of environmental regulations was one of the cost considerations taken into account by the steel manufacturers.

Environmental regulations alone would not have generated a large enough incentive to develop smelting reduction technology. The most important effect of regulations was that they provided the researchers within firms with an additional argument for continuing a specific R&D effort; an additional justification for creating firm-internal support.

2. Agreements

We found two agreements between government and a specific manufacturing firm with regard to the development of smelting reduction technology. Although these agreements as such did not lead to any additional R&D activities, the two firms were well aware of their contract with government. The Dutch steel firm's voluntary agreement on energy efficiency meant that the firm did not want to lose its credibility in dealing with issues like energy efficiency [Meijer, 2000]. In the case of an Australian mining firm, the agreement with government to look for (innovative) technologies in order to add value to the firm's iron ore resources did govern the firms' thinking [Innes, 2001]. We have the impression that the firms felt a commitment to government. It remains to be seen whether agreements on for instance energy efficiency R&D can stimulate technological development.

3. Facilitating contacts between actors and stimulating co-operation

The other strategies listed in Table 13 deal with facilitating contacts, interaction and co-operation between actors. Establishing co-operation between actors (especially between public and private actors) is nowadays seen as an effective strategy for exploiting knowledge [OECD, 1998; OECD, 1996]. There are three examples of co-operative R&D in the empirical material. First, the ECSC's RTD programme supported (co-operative) R&D projects within specific steel micro-networks. It also facilitated meetings between steel firms, who were active in specific ECSC-supported R&D projects. Secondly, in four steel micro-networks[15], multi-partner co-operative R&D programmes were established. Thirdly, the IEA Pulp and Paper Implementing Agreement tried to enhance co-operation between research institutes in the case of impulse technology.

The regular meetings within the ECSC network led to some fruitful co-operative R&D projects, especially in the early stages of developing innovative technologies. This is due largely to the design of the ECSC RTD programme[16]. In spite of this

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[15] Strip casting: Bessemer Consortium and CMU project. Smelting reduction: DIOS and DSM.

[16] The value of the ECSC RTD programme is that there is quite a large target group of steel firms that are all interested in R&D (and in getting their levies back). The steel firms are aware that is valuable to co-operate in the early stages of an R&D project. The ECSC network meetings facilitate contacts between researchers and lower the threshold for contacts. Generally ECSC-supported projects are (co-operative) pre-competitive R&D projects in which actors learn from other experienced researchers and can share expertise, experience and costs. If R&D activities move towards a strategic phase, steel firms lose interest in ECSC support. This has to do with the absolute contribution by the ECSC and with the requirement to exchange R&D results within the ECSC network meetings.

positive role, the R&D projects supported by the ECSC are not always additional (or the projects cover only 'side-lines' of R&D activities).
In three of the four multi-partner co-operative R&D programmes, which were all heavily supported financially by various national governments, firms merely aimed at exploring the possibilities of a technology's promising potential and at acquiring an understanding of the technical difficulties. Actors' primary interest was *not* to bring the technology towards commercialisation.
The IEA implementing agreement, which set up a task group for impulse technology, showed clearly that establishing co-operation between 'competing' research institutes and even formulating pre-competitive R&D tasks can be extremely difficult[17].

To conclude, stimulating co-operative R&D is not an easy way of guaranteeing effective R&D support. The value of stimulating or insisting on co-operation depends on the stage of a technology's development and on the mutual interests and stakes of the participating actors.

4. Network steering: initiating micro-networks?

Another way in which government can stimulate technological development is to change the composition of the technology network or to enlarge the technology network. Figure 1 indicated the dominant role of firms in performing R&D activities. In none of the four technology case studies did government play an *initiating* role in the shift from the exploration stage to the technology network stage. However, government did play a role in enlarging and strengthening both the smelting reduction technology network and the impulse technology network. In the case of strip casting technology, government R&D assistance and some activities and meetings within the ECSC supported the efforts of those who were exploring the possibilities of strip casting technology. Exchange of experiences speeded up R&D activities. A large number of these small-scale efforts came to a halt, but a robust technology network resulted.

In four of the 23 micro-networks, government played a direct role in initiating R&D activities[18]. Two of these micro-networks ceased R&D activities. One of the four micro-networks was critical for the continued development. If this micro-network had not emerged, the development of impulse technology would have stopped completely[19].

[17] The fact that there were no additional financial resources available within the IEA Implementing Agreement did not make things easier.
[18] Smelting reduction technology: 1) DSM micro-network and 2) Australian AusIron micro-network. The Romelt micro-network is not included (developed in former USSR). Impulse technology: 3) STFI micro-network. Strip casting technology: 4) Armco micro-network.
[19] A government official was important in initiating R&D activities in the STFI micro-network. He promised substantial R&D support if the research institute would come up with a solid proposal for an R&D programme. It took roughly 6 years before the institute initiated a major R&D programme.

We conclude that information about the size of a technology network can persuade government to stimulate new micro-networks. Government R&D support or the organisation of exchange and meetings may induce a technology network to gain momentum, particularly if a technology network is just emerging. R&D attention for an innovative technology may be anchored.

Summary

Our empirical material leads us to the following tentative conclusions:

- The effect of a regulation was to provide researchers within a firm with an additional reason for creating 'firm-internal' support for initiating or continuing R&D. The incentive, however, was too small to initiate large-scale and complex R&D efforts needed for developing industrial process technologies.
- Firms that had a direct agreement with government showed a certain commitment. It remains to be seen whether agreements on for instance energy efficiency R&D can stimulate technological development. The results merely suggest that it may be an interesting way for government to intervene.
- Stimulating co-operative R&D was additional in most multi-partner micro-networks, although it did not accelerate technology development. Actors' involved in a co-operative R&D project (in most micro-networks competitive manufacturers) did not intend to commercialise the technology. The value of stimulating or insisting on co-operation depends on the stage of a technology's development and on the mutual interests and stakes of the participating actors.
- Government R&D support contributed to the anchoring of the technology network and to the enlargement of the technology network.

Note that the empirical evidence is too limited for us to draw strong conclusions. Additional (case study) research needs to be done on the various types of government intervention strategies.

## 7.3. Lessons for technology studies and energy analysis

In this thesis we draw on two disciplines that have a different perception of technology. Energy analysts see technology primarily as hardware with some favourable performance characteristics. Scholars in technology studies, on the other hand, see technology as the outcome of a social process. We have not tried to unify these two different perspectives. We started from one discipline – energy analysis – and argued that it would be useful to take a look at the insights generated by technology studies. In the empirical case studies we were able to weigh up the effect of government intervention as an element in the social shaping of industrial energy-efficient technology. In this section, we briefly discuss some findings that are valuable for technology studies and energy analysis.

## Technology studies

It was not our main purpose to generate theoretical insights for technology studies. However, we summarise some contributions explicitly.

Slow technology

Our research has given us a better understanding of the dynamics of technological development in manufacturing industries, which has remained relatively unexplored in technology studies (see e.g. [Jasanoff, 1995])[20]. The development of innovative technologies that affect the core of the manufacturing process is relatively slow compared to other domains of technology. In this thesis, we have identified a few interconnected factors that restrict the dynamics in technology development:

- The capital invested in the existing, proven manufacturing production processes constrains actors in their R&D activities.
- The existing production process is relatively homogeneous. This constrains the variety sought after in technological development.
- Innovative technologies may be known for a number of decades, yet remain in the exploration stage.
- Innovative technologies have to be recognised as a next-step-to-take in improving the performance of the existing production process. Only then does a technology network emerge. Four (preliminary) factors that may contribute towards the shift from the exploration stage to the technology network stage were identified. This is an interesting topic for further research.
- All technology networks are rather small. There are a limited number of players. The micro-networks developing the technologies are quite stable.
- The number of competing innovative technologies is generally also modest for such manufacturing industries. There is no business logic in developing a larger number of competing innovative technologies at the same time. Furthermore, an innovative technology often leaves considerable space for important improvements after it has been introduced. The cycles for developing new process technologies are long i.e. twenty to forty years.
- It takes time, financial resources, continued effort and patience to get an innovative technology accepted as a proven technology in the manufacturing industry. A continuous up-scaling, most often two or three steps easily taking about 10 to 20 years, is required to convince the manufacturing firms. They are prone to take risks.
- The majority of the manufacturing firms become interested only when the innovative technology is ‘proven’. Innovative process technologies are typically first implemented in existing facilities. It can take a considerable time (10 to 15

[20] Recently Moors (2000) also reported on technological development in mature industrial sectors. Moors focuses on the conditions that determine whether technology choices lead to incremental or more radical solution directions (iron and steel, aluminium and zinc production).

years) before a technology becomes a proven option for the entire range of products manufactured in a specific industry.
- The number of actors able to develop core process technologies is not too large. Actors with a 'proven' reputation in technology development appear to have a better chance of getting an innovative technology introduced. This, however, is an issue requiring further research.

Radical innovation should become incremental

In technology studies, the question of whether an innovation is 'radical' or 'incremental' is perennial (for a more elaborate account of various distinctions between more radical or less radical innovation, see Chapter 2, footnote 11).
In the manufacturing industry, however, the radical nature of an innovative technology is not a static characteristic; each radical technology has to become more incremental before it is considered seriously for technological development. An innovative technology that was one day considered as not feasible – 'an unbelievable idea' –, may become the 'next-step-to-take' as time goes on. The notions of radical and incremental are evaluated through the eyes of the actors involved in developing the technology. A technology becomes 'more incremental' if an actor or actors really recognise it as an economically attractive and technologically feasible improvement to the existing production process (the sequence of conventional process technologies).

Distinguishing the exploration stage from the technology network stage

Developing innovative process technologies takes a considerable time. In all four technology case studies the time-frame between first idea and moment of innovation could be divided into an exploration stage and a technology network stage. Innovative technologies may slumber for decades (in spite of the fact that serious R&D activities occur) before a robust technology network really 'takes off'. Only then does the idea become entrenched and the technology remains a priority in R&D for a substantial number of years (in only one or possibly more micro-networks). The shift from the exploration stage to the technology network stage is an interesting topic that requires further research (e.g. testing the four preliminary factors that affect this shift and researching the possible ways in which government can enhance this shift).

Stratifying levels of analysis

Several authors (see e.g. [Green et al., 1999; Rip and Kemp, 1998]) have recently claimed that the meso-level might be an interesting level for government intervention. Our findings underpin this claim. Our research shows how useful it is to distinguish micro-networks as elements within a technology network. These micro-networks turned out to be stable entities over fairly long time periods. R&D activities were concentrated within such micro-networks. Often close interaction occurred between the actors within micro-networks. Micro-networks actively monitored the R&D activities and successes and failures of other micro-networks. As Green et al. (1999) also suggested, the value of such a stratification is that it pinpoints the place where actors are active, it maps the distributed process of technological development, and places these activities against the background of ongoing technological development. We think such stratified networks can reveal the points at which government can intervene to further technological development.

Closure is not necessary

A well known concept in technology studies is the concept of closure [Bijker, 1987]. The idea behind this mechanism is that actors have different interpretations about the same artefact and that this interpretative flexibility has to be reduced. Our analysis of developing energy-efficient technologies, however, has illustrated that closure of the interpretation of a technology may not occur. On the contrary, maintaining a variety of interpretations and selectively using a specific interpretation can be fruitful in, for instance, mobilising external R&D support. Each of the actors can stress or recognise the promising performance characteristics that suit his/her purposes best. Avoiding closure creates space for strategic behaviour by actors.

## Energy Analysis

In energy analysis, one typically compares systems of technologies in order to evaluate which systems and which technologies may reduce $CO_2$ emissions at what costs. The discipline of energy analysis is still developing (see e.g. [Blok, 2000]). In this thesis, we have developed some insights and concepts that are useful for future energy analysis.

Our analysis makes it very clear that energy analysts, in compiling their system analyses, have a rather specific way of looking at and dealing with energy-efficient technology. Although energy analysts are to some extent aware that most innovative energy-efficient technologies that affect the core of the manufacturing process do more than improve energy efficiency alone, we saw in our analysis that energy-efficiency considerations played a minor role. Most of the manufacturing industries attach importance to other performance characteristics than those stressed by energy analysts.

Energy analysts should be explicit about the reliability of their energy-efficiency data and investment cost data. Lab scale efficiency data are sometimes the best data available for energy-efficiency calculations (see e.g. [Gilbreath at al., 1995; De Beer, 1998]). However, such data are often not at all accurate with regard to energy use on a commercial scale. Data can also be flawed as a result of optimism; it can be in researchers' interest to present certain data in order to mobilise other actors. Often data are kept secret. The amount of data available is typically limited. If data are available one should double check the source in order to evaluate their reliability. Note too that performance data are not static.

An innovative technology is not often directly applicable in the entire manufacturing sector. In practice, an energy-efficient technology may at first only be implemented in a specific part of the total production capacity (i.e. only for specific steel or paper grades): it takes time before an innovative technology can be applied in the entire sector. What is considered as a proven technology in one part of the sector is not necessarily proven for all manufacturing firms[21].

A reference technology is not static, nor is the reference technology always clear. The performance of the conventional production process may improve over time (due to the implementation of other technologies or other improvements). The selection of a reference technology by energy analysts shows what they see as the most logical competing technology. The ‘real’ reference does not always match with what the energy analysts define as a reference technology. Smelting reduction technology is for instance not competing with new coke ovens and blast furnaces but with a continuous upgrading of these facilities. Furthermore, the reference technology for application of smelting reduction technology in mini-mills is different from the reference technology in integrated steel mills.

In both manufacturing industries innovative technologies are first implemented in existing paper mills or existing steel sites. Energy analysts often recognise that renewing the industrial capital stock is a process in which components are gradually replaced. The difference between retrofit and replacement, however, is fuzzier than often assumed. It would be useful to gain more insight into the differences in investment behaviour of firms with regard to ongoing small capital investments to improve the existing facilities or major capital investments (such as implementing a shoe press).

Because data availability is limited and energy analysts typically refer to a limited number of data, an important strategy for good data gathering in energy analysis is to maintain a (personal) network with industry experts. Energy analysts are advised to consult experts and scientists who are actually working in developing (or selling) the energy-efficient technologies. Maintaining a network will render a lot of tacit knowledge and understanding about the chances and limitations of the energy-efficient technologies concerned. Moreover, such contacts and interaction will provide them with relevant (and recent) additional techno-economic information.

A final suggestion is that energy analysts should look for innovative technologies that are still at an exploration stage; currently most of their efforts are concentrated

[21] This happened not only in the case of shoe press technology, but also in the case of conventional continuous casting technology and thin slab casting technology (both steel industry).

on innovative energy-efficient technologies that are in the technology network stage. Energy analysts should try to produce more innovative ideas with regard to the reduction of energy consumption for manufacturing energy-intensive products. We realise that it is not easy to make an inventory of radical ideas that are still in the exploration stage. However, this is a major challenge; there is not only much to gain in terms of energy efficiency, but if government can enhance the emergence of technology networks, there is also much to gain in accelerating technological development. It is not only important to know in what part of the production process the largest energy savings are possible (use exergy analysis). It is also important to consult (international) industrial engineers and researchers who have been involved in process technology R&D for a considerable number of years. Such people typically have ideas that go beyond the 'next-step-to-take'.

## 7.4. Possibilities for government intervention

Our detailed study of four sector-specific innovative process technologies for the manufacturing industry and the insights generated by comparing them lead us to draw four policy-relevant conclusions. From these conclusions, we continue our exploration of how government can improve the effect of its intervention to stimulate technological development. We finish by giving some recommendations to enhance the effect of government intervention in the case of major energy-efficient process technologies for the manufacturing industry.

### Policy-relevant conclusions

Our first conclusion regarding technological development in the manufacturing industry is that actors are strongly constrained by the existing production process.

The innovative process technologies considered in this thesis are major process innovations. These are only developed if they are recognised as the next-step-to-take for improving the performance of the existing production process (the conventional route of manufacturing the product). Thus, the existing production process tends towards system optimisation rather than to the complete renewal of the production process. It may happen that an innovative technology induces or reinforces the emergence of an alternative production route for a specific product. However, such a bifurcation in production routes appears to be an exception – and also a long-term process that is not accomplished by one specific innovative technology[22] –, rather than a regular occurrence in mature manufacturing industries.

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[22] Think for instance of the introduction of smelting reduction technology in the steel industry. This may reinforce the competitive position of mini-mills over the conventional integrated mill route. More than one innovative technology is often needed to induce a new production route. The alternative mini-mill steel route has emerged more distinctly over a time-period of twenty years.

Our second conclusion, closely related to the first, is that technological development takes a considerable time. Ideas about innovative technologies may slumber for decades. Subsequently, it takes at least ten to fifteen years (often longer) before the technology is ‘proven’ on a commercial scale. Acceptance of the technology as the proven design for all firms in a manufacturing industry may take another ten to twenty years.
Capital intensity and business pressure are typically referred to as the major factors that slow down technological development in manufacturing industries. The number of competing innovative technologies is typically limited. Often there is only one and there are always fewer than five competing innovative process technologies. Also, the number of actors developing and commercialising innovative technologies is usually restricted. Most often (well-known) firms initiate and support the development of innovative technologies in spite of the long development times.

Our third conclusion is that *effective* stimulation of the development of industrial energy-efficient process technologies is not easy.
The desire to implement effective intervention strategies is what makes stimulating technological development problematic. Although effective intervention is not impossible. On the one hand, we noticed that firms usually recognised the advantages of the technology for their business and identified a technology’s potential to improve the existing production process. Government R&D support was not always additional, or was only additional in micro-networks that were (intentionally) not operating at the frontier of the technology’s development. On the other hand, we also found case studies where government intervention was effective; R&D support was additional and led to enlargement of technology networks. In a specific case study it even led to faster technology development.

Our fourth conclusion is that there is considerable variety in the technology networks that develop the energy-efficient technologies. The general promise of *innovative industrial energy-efficient technologies* masks heterogeneity.
Labelling innovative energy-efficient process technologies as energy efficient is somewhat misleading. Most often, the label does not reflect actors’ real arguments for developing the industrial process technologies. It also neglects the diversity between various manufacturing industries. The four technology case studies showed that the effect of government intervention depended on the characteristics of the technology network. There was variety in the size of the technology networks, the type of actors involved, the geographic distribution of R&D activities, and the momentum of the networks. Therefore, there is no simple recipe for government intervention that can be applied to all energy-efficient technologies in all the manufacturing industries. There is no ‘one size fits all’ strategy for accelerating technological development. Thus, government should take into account the characteristics of the technology network before deciding *if* and *how* it should intervene.

## Increasing the effect of government intervention?

There are two important dilemmas that need to be mentioned briefly before we comment further on how the effect of government intervention can be improved.

The first dilemma is whether government should play any role in stimulating the development of such industrial process technologies. Our research results seem to indicate that government should not intervene in the case of technologies that affect the core of the production process. All developments are driven primarily by market considerations and, thus, developing these innovative technologies is primarily a task for the firms operating in these markets.
The second dilemma is whether government adopts a generic or specific intervention strategy. At the moment, the dominant trend in stimulating technological development (in energy R&D) is that the 'market' should decide in selecting technologies for R&D and commercialisation. The government has a poor record in picking 'winning' technologies. The risk of government failure in implementing specific intervention strategies is large. Therefore, generic intervention strategies are favoured.

With regard to these dilemma's we agree upon the suggestion that firms should play a dominant role in selecting and investing in the development of such industrial process technologies. We also recognise the difficulties for government to design specific intervention strategies. However, in particular cases government intervention can be crucial to gain momentum or to make the next step in up-scaling equipment. The societal importance of further improvements in industrial energy efficiency and the somewhat disappointing effect of government intervention in stimulating the development of such technologies so far make us wonder how the effect of government intervention can be improved: *if* government does decide to intervene, then its effect should be increased.

The diversity between the manufacturing industries and various technology networks calls for government intervention strategies that are better tailored to the networks of a specific industry. As indicated before, there is no standard recipe for government intervention that can be applied to all energy-efficient technologies in all the manufacturing industries and that can be implemented successfully by various national governments. National governments should have a thorough knowledge of the (international) technology networks and of the role and capacities of actors that they can address before deciding *if* and *how* to intervene.
We do not intend that stimulating technology development can always be effective (in terms of accelerating technology development or improving energy efficiency). After all, technology development is uncertain. We do not intend that government have to select the 'innovative process technologies that industries need'. We do suggest that information about patterns of innovation and international technology

networks can provide (more qualitative) insight that is valuable for improving the effect of government intervention.

We do not take the view that government intervention is needed in the case of all energy-efficient technologies. On the basis of information about the technology networks, governments may also decide *not* to intervene. In addition, we realise the importance of generic intervention, which can for instance create favourable framework conditions for the efficient and dynamic functioning of free markets, remove market imperfections, lead to investments in fundamental R&D and the training and education systems, create openness to international flows of goods, people and ideas, and attract foreign investment in R&D.

We have no intention of formulating concrete policy proposals or of designing specific policy instruments. In this section, we provide general recommendations and ideas for improving the effect of government intervention directed at technological development in manufacturing industries.

1. <u>Access to actors</u>

Developing and commercialising innovative technologies in the manufacturing industry is an international affair. Business relationships with suppliers and engineers and the contacts in R&D networks extend beyond national borders. At the same time, there are usually a limited number of micro-networks in a restricted number of countries. In the case of small countries, such as the Netherlands, the chance is large that the majority of the industrial energy-efficient technologies will be developed in foreign countries. Most governments do not have a direct access to technology networks. The opportunities for governments to accelerate technology development or to enlarge or change the structure of the technology network depend on governments' access to actors that that can play a crucial role in the international technology network.

Therefore, it is important for each government to know what specific knowledge and R&D experience regarding various manufacturing industries and industrial process technologies are available within a country[23]. It is also important to know which (national or international) actors *typically* deliver innovative process technologies to specific manufacturing industries. These actors are not necessarily the only ones able to commercialise technology, although it is likely that these actors are eventually needed to prove the feasibility of a process technology to the manufacturing industry. If government has direct access to an actor within a micro-network or to actors that are capable of initiating a new micro-network (with some impact on the technology network), government can directly meet these actors in order to see if and how it can stimulate the technology's development.

[23] Government should have a detailed insight into the competitive position of particular research areas or technology fields in a wider international context.

If government has no direct access to relevant actors there are two alternative intervention strategies.
First, national governments always have *indirect* access to technology networks. They can always deploy intervention strategies that affect actors who in their turn may express preferences (on energy efficiency) to the international actors that are directly involved developing process technologies. Government can for instance decide to continue a stringent policy regarding voluntary agreements on industrial energy efficiency for specific manufacturing industries. Such indirect 'pull' strategies make use of the economic interdependency of firms. Government articulates a specific selection requirement by stressing energy efficiency, so that manufacturing firms convey this R&D criterion to their suppliers. Government can also try to create contacts and exchanges between international technology developers and the national manufacturing industry or to ensure that regular information is made available about the performance of innovative energy-efficient technologies. In this way, firms are informed about recent achievements and performance of innovative energy-efficient technologies. National research institutes may play a role in organising such exchanges and interactions. When applying such indirect strategies, government has to be realistic about the goals that are achievable; it is not guaranteed that these intervention strategies accelerate the development of energy-efficient technologies.

Second, national government may join forces in stimulating the development of industrial energy-efficient process technology. International R&D programmes should prove interesting because a larger target group of actors with similar research interests and capacities for developing process technologies can be addressed. We are aware that national interests and stakes may hamper the realisation of such an international approach. However, in such international R&D programmes, it is a good strategy to enhance co-operation and meetings among actors in *pre-competitive* research areas. Actors meet, exchange information and R&D experience and initiate R&D projects. Government R&D support or the organisation of exchange and meetings may induce a technology network to gain momentum, particularly if a technology network is just emerging. A further step would be to compile international R&D programmes for all stages of R&D activities. Another possible international strategy is for international bodies to map the international technology networks of major energy-efficient process technologies. It is not in the interest of any of the separate countries to perform such an exercise individually. In line with this suggestion, it should be possible to develop accurate technology network 'indicators' that reflect the interactions and decisions of actors in developing technology and permit the monitoring of changes in technology networks.

## 2. Momentum and timing

We introduced the concept of momentum in order to capture the dynamics of technology networks. Momentum is a technology network characteristic, not a characteristic of the technology. It is a measure that reflects the confidence actors have in the development of a particular innovative technology. The momentum of technology networks gives a first indication whether government should intervene at all (see Figure 6)[24].

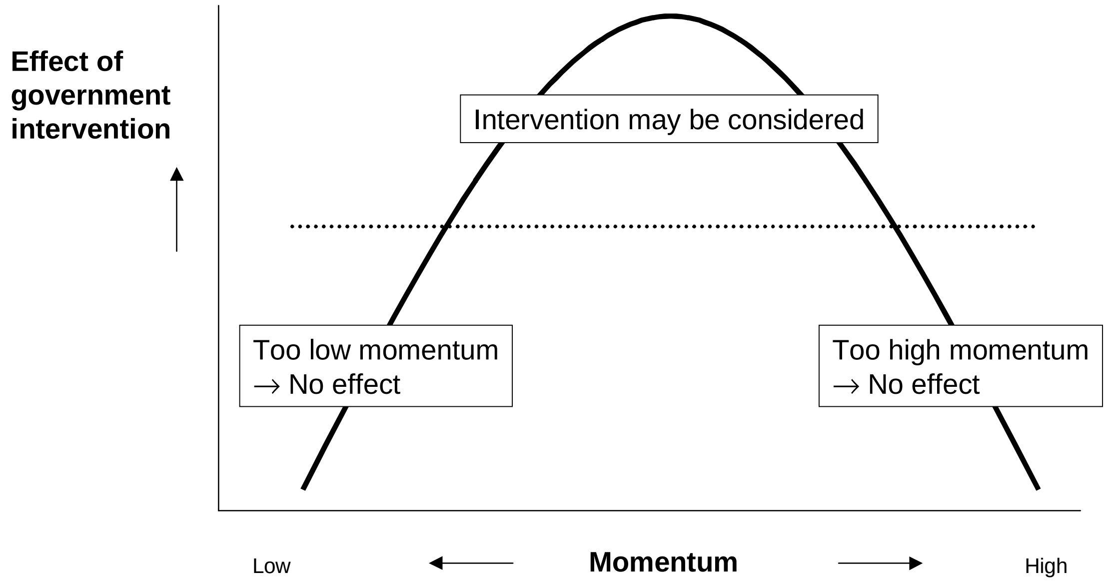


*Figure 6:* *Using momentum as an indication about whether government intervention is likely to have any effect.*

If the technology network's momentum is high, government intervention is not likely to have much added value. The actors involved are confident that an innovative technology will continue to be an interesting option. In such circumstances, financial government R&D support is very likely to support 'free riders'. If the technology network's momentum is low, government intervention is not likely to be effective either because there is very little chance that a technology will become a proven technology in the end. The risk of ending up with a 'white elephant' is too large.

Momentum is a characteristic of the technology network that may change over time. This implies that the effect of government intervention will be influenced by the moment or time at which it occurs. By monitoring how a technology networks' momentum changes governments may be able to select the best moment for contributing to the development of an energy-efficient technology.

Note that a government's decision on how to intervene in a technology network needs to be based on more than information about momentum. For instance, information about the size of a technology network and about government's access to actors are important for deciding on the way in which government can stimulate most effectively.

[24] If momentum is used as an indicator it needs to be measured. We have referred to difficulties and possible strategies in measuring momentum in Section 7.2.

3. Patience and critical attention

As was already indicated, developing industrial energy-efficient process technologies takes time. Even if a technology was in the technology network stage, a time-frame of ten to twenty years is no exception.

When the momentum of a technology network is modest and the technology promises substantial improvements in energy efficiency, long-term government commitment to innovative process technologies is required. Government has to be patient. This patience should not be confused with a naïve belief that a commercial technology will eventually result. Acquiring R&D support should never become the driving force in R&D efforts. If the development of an energy-efficient technology has gone on for *more* than 5 years or if actors keep coming back for R&D support and have taken no serious step to up-scale the technology, government has to be cautious about continuing financial R&D support.

If government has financially supported the development of a major energy-efficient technology for a long time, it must monitor the changes in the international technology network actively before deciding whether to continue R&D. A government should not evaluate an innovative technology simply in terms of its promised energy-efficiency performance only; it should monitor the progress in R&D, the steps in up-scaling, the (changes) in the momentum of technology networks and the position and stakes of the actors involved.

4. Government's own agenda

All four energy-efficient process technologies were developed for reasons other than the improvement in energy efficiency. The fact that actors' and governments' agendas differ is not a reason for failing to stimulate the development of industrial energy-efficient technologies. Government intervention may still be legitimate and effective.

However, government has to protect its own agenda in terms of its primary interest, namely energy-efficiency improvement. Government should have a thorough (and independent) insight into energy-efficiency improvements and also into the other (more) promising performance characteristics. It should have insight into the priority attached to various performance characteristics. Claims about energy-efficiency improvements have to be evaluated critically. A supply of external independent information may be important in this regard. In the case of such process technologies, it is not always easy to find independent experts who know enough about the technology to make a proper and independent assessment.

In a similar way, it is important to understand what an innovative technology implies for the existing production process. As pointed out earlier technological development is severely constrained by the existing production process. In other words, in developing industrial process technologies it is not easy to avoid a 'lock-in' to a further optimisation of the conventional energy-intensive production route. The majority of the innovative technologies optimise the performance of the existing production process. They tend to 'system optimisation' rather than to a complete renewal of the existing production process. Insight into the consequences of the innovative technology for the production process – in relation to competing innovative technologies and improvements in the existing conventional technologies – should help a government to decide whether it should or should not stimulate the development of specific technologies.

5. Flexibility

In stimulating technological development via R&D programmes, governments are usually restricted by a number of conditions, such as the absolute size of a budget, the eligible target groups, requirements on co-operation in R&D or requirements regarding co-investment by firms. Often national governments cannot spend more than a certain percentage on government R&D support. Often, there are good reasons for these conditions, although in stimulating the development of industrial energy-efficient technologies governments need a certain degree of flexibility in designing a tailor-fit strategy.

For instance, it is not always needed to involve or focus on the energy end-users. In some sectors, manufacturing firms are not likely to be the type of actors that will bring about technological development or will deepen specific R&D knowledge. 'Incremental' improvements may occur if such manufacturing firms have a (decisive) voice in selecting R&D projects or R&D areas at a national level. The majority of such market actors may be influenced by short-term goals rather than by the long-term perspective that is needed for investing in R&D and developing process technologies.

Government can play a role in supporting a demonstration facility. If a technology network's momentum is moderate, if the innovative technology is likely to be technically feasible, and if it promises substantial energy-efficiency improvements, government intervention may be an additional factor in proving the performance of the technology. The gain in terms of accelerating a technology's development can be large. At this stage, there is typically a considerable budget at stake. Normally, however, both budget constraints and limits on a government's maximum contribution prevent government from providing finance for a demonstration facility.

If a government considers supporting a demonstration project, it is, of course, a very cost-effective method for exploring the status of the (international) technology network first. In this way, the effect of government support in the technology network can be evaluated in advance. Government should only engage in realising a demonstration facility if there is a large chance that its commercial introduction is accelerated considerably.

## 6. Beyond R&D support

In Chapter 2 (Section 2.3, Box 1, and Section 2.4), we indicated a number of alternative policy instruments and strategies that could be used to stimulate technological development. We found only limited empirical evidence for such policy instruments. We now suggest some possible ways in which these instruments could affect the development of industrial energy-efficient technologies.

We have the impression that neither regulatory instruments (standards and voluntary agreements) nor economic instruments (taxes and fees) are likely to initiate the large R&D efforts needed to develop process technologies for the manufacturing industry. In the case of most energy-intensive manufacturing industries, improving energy efficiency is not a decisive argument for developing a technology that affects the core of the production process[25]. However, all these instruments do draw attention to industrial energy efficiency. They articulate what government finds important and, as such, may increase interest in industrial energy efficiency (also with regard to innovative process technologies). It is not likely that implementation of such policy instruments will accelerate development of energy-efficient process technologies (by the manufacturing firms themselves or supplying industries). As was indicated before, policy instruments that affect the demand for technological innovation may be the best option if a national government cannot directly address the actors who play a role in the development of a major process technology.

Policy instruments that initiate networks and require co-operation between different types of actors can be useful, but also have their drawbacks. Stimulating co-operation in developing industrial process technologies, especially in multi-actor co-operative R&D projects, does not always accelerate technological development. The actors involved do not aim at commercialising the technology, they merely learn about the promising possibilities of an innovative energy-efficient technology so that they are better informed for making future R&D (or investment) decisions. Insisting on co-operation appears to be most valuable in pre-competitive R&D activities. At this stage, actors have a stake in 'learning through exchange'. The added-value of co-operation and interaction will depend largely on the stakes of the actors and the target group of actors addressed.

Other policy instruments available are R&D contracts or R&D agreements with specific actors that can make a difference in the energy-efficiency performance of innovative technologies for the manufacturing industry. By using such instruments, government tries to increase the priority attached to energy efficiency as an important R&D criteria in ongoing technological development activities. Information is needed about actors that typically deliver innovative process technologies to the manufacturing industry. International action and co-ordination are also required. In

[25] In most of the energy-intensive manufacturing industries, energy costs do not rule day-to-day operation of the production processes.

the case of the pulp and paper industry, European governments may for instance try to commit the European machine suppliers to a certain R&D agreement on energy efficiency.

To conclude, it is not easy to dispense whereas spending financial R&D support effectively, nor is there any guarantee that other policy instruments will be successful in stimulating the development of industrial energy-efficient technologies. Although, these may be better tailored to the networks of a specific industry. Alternative intervention strategies permit government to articulate the importance they attach to the energy efficiency of innovative process technologies directly to the actors who can be addressed.

## 7. Strategies in the exploration stage

In our analysis of the development of industrial energy-efficient technologies, we made a distinction between the exploration stage and the technology network stage. Government has much to gain if it can accelerate the moment that a technology network arises.

It would be interesting to find a way to activate R&D for technologies that are still at the exploration stage. In other words, it would be interesting to support the advancement of technologies that are not yet seen as the ‘next-step-to-take’. Government may develop strategies so that technology networks gain momentum earlier. Experienced researchers from commercial or semi-commercial R&D labs who have successfully contributed to the development of process technologies for a specific manufacturing industry could perhaps be granted a sabbatical during which they are expected to come up with new ideas for stimulating industrial energy efficiency. ‘Radical variation’ in a protected environment can be stimulated by giving financial support to experienced researchers with a thorough knowledge of the manufacturing process.

Again, one needs to be aware of the stage that the innovative technology has reached. If a technology network is just gaining momentum as it has only recently emerged, an attractive strategy is to provide some firms or research institutes with some ‘seed’ grants in order to reinforce a more robust technology network. This is also the stage when it is interesting to reinforce the technology in the industry’s ‘R&D agenda’. The stage that the innovative technologies have reached is also an important indicator for evaluating the composition of a government’s R&D portfolio.

### Know the technology networks

In spite of the difficulties to stimulate the development of industrial energy-efficient technology effectively, it remains a major opportunity in mitigating greenhouse gas emissions. Energy efficiency with regard to innovative process technologies deserves (and requires) further attention by government. The fact that an innovative technology is labelled as energy efficient is insufficient to make governments to decide if and how to intervene. Energy efficiency is possibly the government's reason for being interested, but this does not say anything about whether government can stimulate or accelerate the development of industrial energy-efficient technologies.

An analysis in terms of technology networks clarifies what governments can do; it casts a light on their room for manoeuvre and reveals whether *if* and *how* governments can intervene (most) effectively to stimulate the development of energy-efficient technology.

National governments should have a thorough knowledge of the (international) technology networks and of the role and capacities of actors that they can address before deciding *if* and *how* to intervene. Depending on the characteristics of the technology network – its momentum and size – and depending on who can be approached and what role actors can play in developing energy-efficient process technologies, governments can decide to support R&D or to influence technological development by other intervention strategies. Box 1 summarises what a government should know about a technology network.

To conclude, the analysis in this chapter has shown that government needs thorough insight into both the technical and the social aspects of technological development if its intervention strategies are to be successful. It has to look beyond industrial energy efficiency. It is important to develop strategies that are able to support, strengthen and affect actors and networks and, thereby, lead technological development in the manufacturing industry in less energy-intensive directions.

**Box 1: Exploring technology networks - deciding on government intervention strategies**

Explore the technology network in order to:
1. assess a technology network's momentum
2. evaluate government's access to actors
3. value the importance and impact of an innovative industrial process technology on the conventional production process

Use the following (preliminary list) of questions:

Actors:
- How many micro-networks (size) are active? Where are they located?
- Which actors are involved: look at the type of actors, the reputation of actors in establishing innovation in that specific manufacturing industry, and at actors' capacities and resources?
- Who can be addressed by a national government, what is their (possible) stake in the international technology network?
- Do actors actively exchange knowledge and information about the technology? How much is published about the technology? How widely known is the technology within the manufacturing industry?

Agenda:
- What are the performance characteristics of the innovative technology and how do they compare with those of the conventional production process: look at both energy-efficiency and other performance characteristics
- Which promising performance characteristics are driving the technology's development?
- How do the perceived performance characteristics develop within the technology network? Are there many data available (this provides information about the secretiveness of a development)?
- Does the innovative technology solve a pressing problem in the existing production process?

Artefact:
- How long has R&D been going on? Has the technology network emerged recently or is the technology about to be introduced commercially?
- How many steps are needed for up-scaling the technology (be explicit in the measure chosen for indicating different scales of facilities)?
- What is the impact of the technology on the various stages of the existing production process? Is the technology a core process technology (how many essential production stages does it replace) or is it an 'added-on' technology?
- Are there competing innovative technologies and how do these and the conventional technology develop?

Momentum:
- What do experts consulted say about the momentum of the technology network of a specific technology (compare with conventional technology and competing innovative technologies)?
- Is the technology widely acknowledged as the next-step-to-take?

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# Chapter 8

# Summary and conclusions

## 8.1. Introduction

The intensive use of fossil fuels within modern society is an example of the close linkage between technology and human activity. The exploitation of fossil fuels within the energy system is causing serious environmental problems such as human-induced climate change. On the one hand, technology allows the extraction, exploitation and use of the fossil fuel resources. On the other hand, innovative technology may facilitate the transformation of the energy system into a more sustainable practice by reducing $CO_2$ and other greenhouse gas emissions. A wide variety of technology options have been suggested, such as energy-efficient and material-efficient technologies, renewable energy technologies, and carbon sequestration. The hope is that in the long run technological development and innovative technology will bring about tremendous improvements and resolve the apparent current conflict between environment and economy.

In this thesis we concentrate on industrial energy-efficiency improvement as one of the promising technological options for reducing greenhouse gas emissions. Improving industrial energy efficiency is acknowledged a cost-effective option for reducing $CO_2$ emissions. It can also lead to lower production costs for the manufacturing industry. Governments find industrial energy efficiency an attractive R&D option. Whereas spending on government energy R&D support has generally fallen off, government R&D support for industrial energy efficiency has been increasing. This raises the question of how government can contribute towards the accelerated development of climate friendly innovative technology.

The effect of government intervention on the development of industrial energy-efficient process technologies is an unexplored area for empirical research. In stimulating industrial energy efficiency one needs to relate a policy instrument to the amount of energy saved due to that instrument. This is not an easy thing to accomplish. First, in evaluations of policy instruments for stimulating the implementation of proven energy-efficient technologies analysts start from plausible assumptions or calculations about the behaviour of actors with regard to investment in such technologies. However, there is no insight into actors' investment behaviour with regard to the development of innovative industrial energy-efficient technologies. Secondly, in evaluating the effect of government intervention in stimulating technological development one encounters a problem of attribution. There is often a considerable time lag between the moment of intervention and final effect in terms of energy efficiency. Therefore, we need to obtain a better understanding of the role of actors and of the dynamics in the process by which energy-efficient process technologies develop. We intend to make a detour. The analysis of detailed technology case-studies let us examine the link between R&D activities, government intervention, actors' decisions and their arguments, and the actual development and materialisation of the technology.

The aim of the thesis is to gain insight into the process by which innovative energy-efficient process technologies for the manufacturing industry are developed. The underlying interest is to explore how government can stimulate the development of such technologies.

We draw on energy system analysis. This discipline provides us with a list of innovative energy-efficient technologies suitable for detailed case study analysis. The way energy analysts perceive technological development and innovation is unlikely to be sufficient for gaining insight into the process of developing such technologies. There is focus on R&D and a strong belief that R&D will provide change for the good. Innovative technology is restricted to a specific piece of hardware with certain performance characteristics. Therefore, we suggest to take a look at the insights provided by technology studies for obtaining guidelines for the performance of the technology case studies.

The thesis has three parts. First, the insights resulting from the various approaches used in technology studies are summarised. We develop a framework for characterising the process of developing an industrial process technology in terms of networks and actors, including the role of government (see Section 8.2). Second, the framework is used for analysing four technology case studies. An important part of this thesis consists of detailed empirical analysis of the networks within which particular process technologies are developed. We selected four industrial energy-efficient technologies from two manufacturing sectors, the pulp and paper industry and the iron and steel industry (see Section 8.3 to Section 8.6). Third, we compare and contrast the insights gained from the technology case studies (Section 8.7) and we explore possible ways in which government can stimulate the development of industrial energy-efficient process technologies (Section 8.8).

## 8.2. Framework

If we want to understand what guides or constrains R&D and technology so that it develops in certain directions and if we want to evaluate the role of government intervention, what should we look for in the empirical material? In Chapter 2 we

developed a framework for analysing the process by which energy-efficient process technologies developed.
An overview of various policy instruments and recent insights gained from policy studies, indicated that the effect of policy instruments cannot be explained by the characteristics of the policy instrument alone. The characteristics of the context in which government tries to intervene are equally important. In order to realise policy goals government is dependent on other actors. The role of government needs to be evaluated as part of the network and compared with the role of other incentives, decisions and dynamics. The choice for detailed technology case studies allow us to evaluate the effect of intervention as part of the social shaping of technology. In evaluating the effect of government intervention, we make a distinction between three different aspects of 'effect':

- Additionality: Government intervention is additional if actors would not have started or continued R&D activities without government intervention. Acceleration: Government intervention accelerates technological development if the progress of the development – worldwide – was faster than it would have been without government intervention.
- Effectiveness: Government intervention is effective if it leads to improved industrial energy efficiency. This is achieved only if the technology is implemented in the end.

For each of the approaches in technology studies, we introduced the basic concepts. Each of the approaches was summarised by indicating three key-points of interest: how is technological development perceived?; what directs technological development?; and what are the possibilities for government intervention?
Instead of opting for one specific approach, we selected aspects of several approaches since they are largely complementary. Common to all the approaches is the idea that technological development can be conceptualised as a social process in which 'Artefacts', 'Actors' and 'Agenda' are constructed and interact. These triple As are summarised as the triangle of technological development. It provides us with a heuristic tool for summarising how scholars engaged in technology studies understand technological development.
Technological development is seen as a process of a social nature. No results are achieved unless actors are willing to invest in or undertake R&D activities. Actors are the vehicles that bring about technological development and innovation. Actors are interdependent. Networks have become the key-concept that links actors. The social process in which technologies are shaped is guided by elements that orient actors by giving priority and direction. Processes of technological development are embedded in what is believed to be a fruitful direction for progress. Technological development is directed by preferences and proven routes in earlier R&D experiences, by the existing production process and by the (business) networks and markets in which actors operate.
The framework should provide us with a structure for understanding who is involved and who interacts with whom – Actors –; for realising what guides R&D and

technological development by understanding actors' arguments for developing a specific technology – Agenda –; and for mapping what results from all these R&D activities and showing how these affect further technological development – Artefacts –.

Figure 1 shows the framework of micro-networks, the technology network and the innovation background. The artefact materialises within the micro-networks. A micro-network consists of one actor or a small group of actors who co-operate in developing a specific industrial energy-efficient technology. The total set of micro-networks is defined as the technology network. The actors are embedded in a context, the innovation background, which influences actors' ideas and perceptions of what is believed to be an interesting direction for progress.

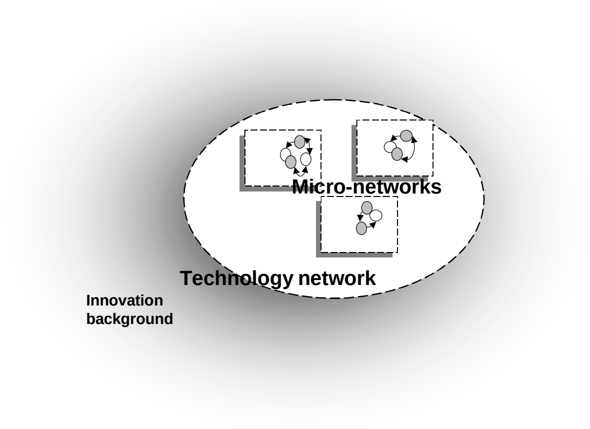



*Figure 1: The network-oriented framework to analyse the development of industrial energy-efficient process technologies.*

We formulated case study questions about the technology network, the micro-networks and the materialisation of the technology. These guided us in performing and analysing the empirical case studies. Finally, the effect of government intervention is evaluated explicitly in each technology case study.

## 8.3. Shoe press technology

In Chapter 3, we analysed the development of shoe press technology. Shoe press technology is a wet pressing technology for the paper industry. It improves dewatering of the board or paper sheet in the wet pressing section and, therefore, reduces the need for evaporative drying. Shoe press technology is one of the major innovations in the paper industry in the 20th century. In the case study of shoe press technology, we focused on the importance of actor characteristics and external factors (such as network linkages between actors and their embeddedness in a specific context) with regard to the development and diffusion of shoe press technology.

The technology network of the shoe press was small; there was just one micro-network. For a long time, the micro-network consisted of one machine supplier.

The US machine supplier Beloit developed the shoe press between 1967 and 1980. It was widely known that time limited the dewatering capacity of the conventional roll presses. However, nobody but the people at Beloit dared to engage in a prolonged effort to develop a new press design to overcome this limitation. Shoe press technology was a tremendous departure from the existing wet pressing design. Beloit's previous R&D activities and engineering experience were of crucial importance for the eventual successful introduction of the shoe press. Only late in 1978 and early in 1980 did a board manufacturer and a fabric supplier became involved. Both were well-known business partners to Beloit. The belt, a crucial component of shoe press technology, was still not available when Weyerhaeuser, the board manufacturer, had already decided to invest in the first shoe press (June 1979). Albany, a fabric supplier, was asked to provide a suitable belt. Albany took on the job of developing and manufacturing a polyurethane-coated belt. Without the belt, the successful introduction of the technology in December 1980 would certainly have been delayed. Developing the technology took about 13 years (1967-1980).

Beloit's major argument for developing shoe press technology was to increase the machine capacity of existing board machines and to reduce the capital intensity in new board machines. Albany perceived the shoe press as an important new technology that could the change the future of wet pressing substantially. The forces that drove Weyerhaeuser were speed-up of the board machine and improved strength properties.

The other international machine suppliers initiated or reinforced R&D activities with regard to shoe press technology when its introduction had become a matter of time (around 1980). The growing technology network led to a fruitful spill-over between machine suppliers and fabric suppliers. Three competing shoe press designs were introduced to the market in 1984, 1986 and 1990. In 1990 four micro-networks, or more specifically four machine suppliers, were active. In 2000, only two machine suppliers were still active in selling shoe press technology.

Beloit's competitors developed an improved design of the shoe press using a 'closed belt'. This closed belt shoe press proved a better performance at higher machine speeds; a continuous increase of machine speeds is what keeps paper and board manufacturers in business. Why did Beloit ended up with an open shoe press in the first place? First, they wanted to introduce shoe press technology as fast as possible. Second, developing the shoe press and solving the belt problem was simply a huge step to take.

Machine suppliers and fabric suppliers continued R&D activities in order to improve the technology and to broaden its application to other paper grades than board. During the 1980s and early 1990s, shoe press technology was applied to board grades only. Machine suppliers tried to convince paper manufacturers of the value of the shoe press for paper grades. Paper manufacturers were risk-averse in adopting

shoe press technology. Although R&D improved the possibilities for application in light-weight paper machines, the shoe press was introduced only when conventional roll presses limited a further increase of the speeds of such paper machines. The first shoe press in a light-weight paper machine was implemented in 1994.
The US government did not contribute to the development of shoe press technology. Beloit did address the US government for covering the risk of innovation in 1980. The energy-efficiency potential of shoe press technology was stressed. The US government was seriously interested, although they were too slow in fulfilling Beloit's request. If government would have covered the risk of innovation its additionality would have been very marginal: Beloit was anyway eager to introduce the technology as fast as possible.
A first conclusion is that actor characteristics were decisive for the successful introduction of the shoe press in the market in 1980. However, Beloit's success was rooted in a broader understanding of the importance of the factor time in wet pressing. Beloit had a thorough knowledge of their customers' needs. And, Beloit had a proven reputation as one of the world-wide major machine suppliers. A second conclusion is that external factors were decisive for ongoing improvements in shoe press technology from 1980 onwards. Further R&D activities and improvements were driven by the market success of shoe press technology.

## 8.4. Impulse technology

In Chapter 4, we analysed the development of impulse technology. Impulse technology is a more recent wet pressing technology for the paper industry than shoe press technology. In an impulse press nip, an *(electrically) heated* shoe press is used to improve dewatering of the paper sheet. In this case study, we evaluated the effect of government R&D support on the development of impulse technology as part of the network in which the technology was developed.
The technology network consisted of two micro-networks (1980-2000). By now, only one micro-network is still active. However, before the technology network emerged, Douglas Wahren, the inventor of impulse technology and the person who suggested impulse technology's special dewatering mechanism, performed R&D activities (1970-1980). He shelved his idea twice before he succeeded in anchoring and extending R&D activities at the US national pulp and paper research institute[1].
Then the first micro-network emerged in North America. The US institute's vice-president was excited about the idea of wet pressing under intense heat and pressure. Wahren initiated R&D activities. The US institute applied to the US Department of Energy for financial R&D support. It was claimed that impulse technology was more energy-efficient than conventional technology. US government R&D support allowed a continued R&D effort at the US pulp and paper research institute (1985-

[1] Such pulp and paper research institutes are financed by a system of member dues. Members are national paper and board companies.

1999). Wahren also contacted some acquainted people at Beloit, the US machine supplier. Beloit started R&D activities. Impulse technology was a logical and interesting step after their successful development and introduction of the shoe press (see Section 8.3). The Canadian pulp and paper research institute also initiated R&D activities in 1983. Impulse technology's dewatering mechanism intrigued the vice-president of the Canadian institute. The Canadians were supported by the national government with regard to their pilot paper machine R&D activities. Again, energy efficiency was as an important argument for obtaining R&D support. Beloit became involved in the Canadian effort. There was an informal agreement between the research institutes that Paprican studied light-weight grades and that IPST studied board grades.

Within this North American micro-network, four attempts to commercialise the technology failed. In the first attempt (1987-1989), Beloit, the board manufacturer Weyerhaeuser and the US pulp and paper research institute tried to jump-start impulse technology. Note that Beloit and Weyerhaeuser successfully introduced shoe press technology. However, delamination of the paper sheet turned out to be a stumbling block. The second attempt occurred in 1992-1993. The leading researchers at the US pulp and paper research institute loudly claimed that they had overcome the problems of delamination. The US Department of Energy was again asked for support. They were willing to support commercialisation on the condition that a machine supplier and a board manufacturer were involved. Beloit became involved again, though none of the institute's member firms was willing for running the risk of being the first in the field. Then, the US Department of Energy agreed to support a consortium of the institute and Beloit. Soon the actors became aware that delamination of board were not controlled yet. Ongoing R&D activities were kept secret. A third attempt for commercialising impulse technology also failed. In 1994, Beloit and the Canadian pulp and paper research institute searched for a newsprint manufacturer to commercialise impulse technology. Lack of interest on the part of newsprint manufacturers was explained by the lack of experience with shoe press technology; investing in *two heated* shoe presses was too big a step to take. Since 1998, the US institute and Beloit have been sharing the research data with board manufacturers in order to commercialise impulse technology. However, the improvements in paper properties were not large enough to outweigh the increase in energy – electricity – costs. This fourth attempt ended when Beloit's mother firm filed for bankruptcy in 1999 and IPST had realised the research tasks they had committed themselves too.

During the late 1980s, R&D interest in impulse technology arose in Europe due to the research results presented by the North American actors and due to the fact that shoe press technology became a proven technology. A Swedish government representative had become aware that impulse technology was a high-risk energy-efficient technology. He offered the Swedish pulp and paper research institute financial R&D support if they would initiate R&D activities. After six to seven years of planning, talking and negotiating, the institute initiated a major R&D programme on impulse technology including a major upgrade of their pilot paper machine (1997-

now). The Finnish machine supplier Valmet is involved in this micro-network. Two other major European machine suppliers did not see any commercial future for the technology.

The major argument to develop impulse technology was to increase the dryness. Wahren's claim implied a tremendous increase in dryness; the machine capacity of existing paper and board machines could be increased and the capital intensity of new machines could be decreased. The national pulp and paper research institutes stressed the energy-efficiency potential of impulse technology in their attempts to obtain government R&D support. Wahren's original claim of increased dewatering capacity became less strong over time. Actors' arguments for investing in impulse technology, thus, also changed over time. By now, paper properties are increasingly stressed.

The financial support given by the US, Canadian and Swedish governments to the three national pulp and paper research institutes has been substantial. Government granted 60 to 65% of the total expenditure in the US (not taking into account Beloit's expenditure between 1981 and 1995); 45% in Canada; and roughly 40% of the major R&D programme at the Swedish pulp and paper research institute. All government R&D support came from budgets for industrial energy-efficiency R&D. In addition impulse technology was seen as a high-risk technology.

However, more than 25 years of R&D and 15 years of government R&D support have not yet resulted in an economically viable technology. In fact, its prospects are uncertain. There is still no agreement on the best method for preventing delamination. The promise with regard to dewatering decreased over time. The original dewatering mechanism is still not proven, neither is its improvement in energy efficiency. Its chance for commercialisation – in its present design – is being debated.

A first conclusion is that the availability of government R&D support undoubtedly accelerated the development of impulse technology. Without R&D support impulse technology would not have reached the state it has reached today. The continued effect of government R&D support depended on the close relationships and co-operation between the actors in the micro-networks. Actors' resources, equipment and capacities were complementary. Regarding the effectiveness of R&D support, we must conclude that the technology's energy-efficiency improvement is uncertain.

A second conclusion is that the strategies and decisions of national pulp and paper research institutes were decisive in the acquisition and utilisation of government R&D support. Government was dependent on these research institutes. In their turn, the research institutes depended on government R&D support for continuing their R&D activities. They stressed the advantages of the technology that government liked most; the technology's promising energy-efficiency potential. The institutes' stakes in performing impulse technology R&D activities were wider than the technology as such - upgrading research facilities and a high-risk R&D programme with a positive exposure of the research institute -. R&D activities drove government R&D support instead of the other way around.

## 8.5. Strip casting technology

In Chapter 5, we analysed the development of strip casting technology. Strip casting technology is an innovative casting technology in steel-making that integrates casting and rolling so that re-heating of steel is avoided. It is the third in a sequence of innovative casting technologies that allow steel manufacturers to cast liquid steel closer to its final product requirements. After the introduction of conventional continuous casting (1952) and the introduction of thin slab casting (1989), strip casting technology is currently at the edge of breakthrough. In this case study, we evaluate the effect of R&D support on the development of strip casting technology. For this purpose, we made a detailed investigation of the networks within which the energy-efficient technology was developed.

The original roots of strip casting technology go back to the 19th century. Bessemer, one of the classical inventors of the iron and steel industry, applied for a patent that covered a twin roll strip caster (1857). Before 1975, there were some localised R&D activities with regard to strip casting technology. However, only after 1980 a robust technology network emerged. The technology network of strip casting technology was quite large and remarkably homogeneous. All eleven micro-networks consisted of a steel firm (producing stainless steel) and a machine supplier or engineer. In most micro-networks, the steel manufacturer took the lead. They also controlled the crucial patents. Six of the eleven micro-networks are still active. Four ceased their R&D activities. Two micro-networks joined R&D activities due to a business merger. Three micro-networks currently operate strip casting technology at an industrial scale (in Japan, Australia and Europe). These three micro-networks needed about fifteen years to reach operation on an industrial scale. They may prove the feasibility of strip casting technology within two or three years; the steel industry is waiting to see how their casters will perform.

The major argument for developing strip casting technology has been the need to reduce the capital intensity of the hot rolling mill. This is especially attractive for small-capacity facilities such as mini-mills and stainless steel facilities. Bessemer already indicated the huge capital advantage of strip casting technology in 1857. Why did strip casting technology not emerge any earlier? The introduction of conventional continuous casting, maturing of this conventional technology, the steel crises during the seventies, the rise of new steel grades as for instance stainless steel and the rise of mini-mills had to occur before strip casting technology became the centre of casting R&D activities. In addition, knowledge became available that could be used to solve some technical problems. Due to the changes technologists and engineers started looking for more compact, innovative casting technologies between 1975 and 1985. They wanted to extend the advantages of continuous casting technology. During the early eighties, a process emerged in which a number of factors – amongst others the claim of success of one of the leading US stainless steel producers – added momentum to strip casting R&D activities. This strengthened internal support in steel firms for initiating explorative R&D. A large number of

small-scale casting efforts were initiated. When thin slab casting technology was commercialised (1989), a technology network that focused on strip casting technology remained active.
Various national governments and the European Coal and Steel Community (ECSC) financially supported the development of strip casting technology. Since 1980, government has supported 5 to 10% of the total expenditure by eleven micro-networks. Six of the eleven micro-networks received government R&D support. In three micro-networks, government R&D support was more than 40% of the total expenditure. However, these three micro-networks stopped their R&D activities or deliberately continued R&D activities on a pilot scale. The three micro-networks that are ahead in developing strip casting technology did not get (or only marginal) external financial R&D support.
The major conclusion of this chapter is that the effect of government R&D support on the development of strip casting technology has been minimal. The development of strip casting technology proved to have a strong momentum of its own. Strip casting affects the core of steel business; its development was only loosely motivated by energy-efficiency considerations or by the availability of external R&D support.

## 8.6. Smelting reduction technology

In Chapter 6, we analysed the development of smelting reduction technology. Smelting reduction technology is the only recent contender to replace the conventional energy-intensive blast furnace that has been the dominant process technology for producing iron since centuries. In this case study, we evaluated the effect of government intervention on the development of smelting reduction technology based on a thorough analysis of the actors and networks involved.
The theory underlying smelting reduction technology has been known since the late 1930s. Only from 1975 did a technology network emerge. By then, other innovative ironmaking technologies had proved disappointing and there was a threat that obsolete coke ovens might have to be replaced at great expense in the beginning of the $21^{st}$ century.
The major argument for developing smelting reduction technology has been that the cost price of a ton of hot metal is likely to be reduced. Lower capital investment (avoiding coke ovens and agglomeration plants and replacing the capital intensive blast furnaces) and the use of coal instead of expensive metallurgical coals are two major factors in this cost price reduction. Energy-efficiency improvements and the threat of environmental regulations (and the necessity to invest in order to comply with these requirements) delivered additional cost advantages for integrated steel manufacturers to be interested in smelting reduction technology. However, these additional cost advantages would never have been large enough to initiate huge and technologically complex R&D efforts such as the development of smelting reduction technology.

Between 1975 and 1985 a considerable number of efforts were initiated, namely between 15 to 20. Most of the efforts were limited to pilot scale activities and the generation of engineering concepts for industrial scale facilities. There was one exception; the Corex process reached commercial application. This is still the only smelting reduction process commercially available. Its techno-economic characteristics limit wide application. Three of these early efforts evolved into micro-networks that studied so-called ‘second generation’ smelting reduction processes that deploy a higher degree of post-combustion and reduce the degree of direct reduction. The technology network consisted of nine micro-networks.

A wide variety of actors played a role. Integrated steel manufacturers dominated four of these micro-networks. Machine suppliers or engineering companies initiated three micro-networks, mining firms initiated two micro-networks and research institutes initiated one micro-network. The technical variety in various smelting reduction processes is rather large. The preference of various actors for the different processes can be explained by their earlier (R&D) experiences with (parts) of the smelting reduction processes.

Six of the nine micro-networks are still active. Three micro-networks stopped; these were all initiated by integrated steel manufacturers. Most of the integrated steel manufacturers who played an active role in various micro-networks lost interest. Existing blast furnaces and coke ovens were continually improved and the lifetimes of the existing stock was extended. The threat that obsolete coke ovens and blast furnaces would have to be replaced did not (yet) come true. They did not need an expansion of their iron production capacity. The cost advantage of smelting reduction technology decreased over time. Smelting reduction technology was ‘locked out’ by a continuous, incremental improvement of the conventional production route and the existing capital stock. However, the future of smelting reduction technology is still undecided; actors like mining firms continue to be interested and there is a growing interest of mini-mill steel operators. Application of smelting reduction technology in mini-mills may be a short-term niche for proving the feasibility of some of the smelting reduction processes. A successful introduction of smelting reduction technology in mini-mills may enhance the market position of the mini-mill route. If smelting reduction technology replaces the processing of scrap, the production of steel in mini-mills will become more energy-intensive.

Various national governments and the European Coal and Steel Community (ECSC) played an active role in the development of smelting reduction technology. We estimate that national governments and the ECSC financed 20 to 25% of the total expenditure by the nine micro-networks. In three micro-networks, R&D support has been larger than 40% of the total expenditure within these micro-networks. In two micro-networks, government intended to grant financial support in connection with the building of two demonstration facilities. The case study also provided some empirical information on the possibilities for government to increase the effect of R&D support by stimulating co-operation. Finally, most integrated steel firms were affected by environmental legislation.

We conclude that government R&D support enlarged the technology network. In five of the nine micro-networks, government R&D support definitely underpinned the performance of additional R&D activities. Three of these five micro-networks developed a smelting reduction process that is likely to be energy-efficient. However, R&D support did not accelerate the technology's development so far. Secondly, the effect of co-operative R&D programmes depended strongly on actors' intentions to participate in such co-operative R&D programmes. Thirdly, we have seen that a commitment by government to support a demonstration facility can be a factor that persuades a firm to demonstrate a technology. Steering in this stage of a technology's development may be an appealing, though highly complex task. In giving a firm and a specific technology a preferential treatment, government should carefully assess whether support may accelerate technological development (in the international technology network). Finally, environmental regulations were not decisive in initiating or continuing R&D efforts. However, they provided researchers and engineers within a firm with an additional argument for continuing R&D.
To conclude, the changes in the technology network reflect the dynamics in the development of smelting reduction technology. Integrated steel firms tend to constrain technological development so that it prefers certain – more incremental – directions. This mechanism considerably limited the effect of government intervention and R&D support.

## 8.7. The dynamics of technology networks

What do we know, now, about the role of actors and of the dynamics in the process by which industrial energy-efficient process technologies develop? We compared the four technology case studies with regard to six issues that relate directly to the framework and to our interest in government intervention.

<u>Actors – Size and composition of the networks</u>
Steel manufacturers and paper manufacturers played a different role in developing energy-efficient technology. The large integrated steel manufacturers invested actively in R&D, whereas the paper firms 'waited' for the international machine suppliers to deliver technologies affecting the core of the paper-making process. The two paper technology networks were smaller than the two steel technology networks. In all four technology networks, there was a dominant role of firms. It was in the majority of the micro-networks that firms co-operated. Co-operation extended itself most often beyond national borders. We have no indication that actors had problems in finding partners. If there were problems, this occurred typically at the stage when the technology had to be proven on a commercial scale.

Artefacts – Time-frame

Developing energy-efficient process technologies takes time. We could distinguish between an exploration stage and a stage in which a technology network was established. It took a while – decades to more than a hundred years – before the innovative technologies were supported by a robust technology network. A combination of factors and mutual reinforcement were needed for the technology network to emerge. We suggested four factors to explain why a shift occurred at a certain moment in time. A first factor is that actors recognise the economic advantage of the innovative technology. This factor is critical, though it is no guarantee in itself. A second and very important factor is the technical need or match with the existing production process. All four innovative technologies were closely linked to the conventional sequence of process technologies. A third factor is progress in R&D and, finally, contingent elements may play a role. The shift typically extends over a few years in which actors acknowledge that the innovative technology may be an interesting 'next-step-to-take'.

Once a technology network emerged, two or three steps in up-scaling the technology had to be taken to prove to the manufacturing industry that a technology is feasible. Each step took at least five years. For two or three up-scaling steps, a time period of 10 to 20 years was not exceptional.

Agenda – Which promises orient technological development?

In both manufacturing industries, the promised reduction in costs per ton product was the dominant argument for investing in the development of the innovative process technologies. The dominant business logic of the majority of steel- and paper-making firms explained the attention for cost reduction. Capital investments already made in the conventional production process strongly constrain the direction of technological development. The existing production processes led to regularity in the technological development; the existing system was further optimised. Note that major innovative technologies were to be implemented in existing production facilities first. The risk of trying out an unproven technology in a new production facility is considered to be too high

Dynamics - Momentum

We introduced the concept of momentum as a characteristic of a technology network. A technology network has a large momentum when it causes observers – analysts like us – to assume that the technology is materialising autonomously. Differences in momentum could be detected in the four technology networks. The momentum of a technology network reflects the confidence of actors in the development of that particular technology. Actors must not lose confidence in the future prospects for the innovative technology. It has to remain the 'next-step-to-take' in spite of possible developments in the conventional production process and in spite of trends and changes in the manufacturing industry. It is crucial for the maintenance of momentum that the actors are re-assured about the benefits for being involved in the first place. The materialisation of the technology, R&D results, claims of success, large difficulties and failures all affect actors' confidence in the future prospects for the technology.

Government R&D support

The financial contribution of government to the development of impulse technology and smelting reduction technology has been substantial (more than 25% of the total R&D expenditure). In the other two case studies, the share is marginal (though not in absolute terms). Energy-efficiency improvement was a major reason for government to grant R&D support. In none of the four case studies was energy efficiency a main argument for actors to develop the technology. Savings in energy costs alone would not have justified the considerable R&D effort needed to develop the four process technologies. The 'promise' of energy efficiency was however actively used to mobilise external (government) R&D support.

We related the effect of government R&D support to the momentum of the four technology networks. The momentum of the technology networks engaged in developing strip casting technology and shoe press technology was high, so government R&D support barely had an additional effect. In such circumstances, it is difficult to intervene effectively. The momentum of the technology networks engaged in developing smelting reduction technology and impulse technology was lower, so government R&D support led to additional R&D activities and enlarged the technology networks.

Government did never play a role in the exploration stage of developing the four technologies. Government contributed to the emergence of technology networks in some case studies.

Alternative government intervention strategies

The empirical material with regard to alternative intervention strategies is scarce, although it leads us to the following tentative conclusions. The effect of a regulation was too small to initiate large-scale and complex R&D efforts needed for developing industrial process technologies. However, it provided researchers within a firm with an additional reason for creating 'firm-internal' support. Firms who had a direct agreement with government showed a certain commitment. Agreements regarding energy-efficiency R&D may be an interesting way for government to intervene. Stimulating co-operative R&D was additional in most multi-actor micro-networks, although it did not accelerate technology development. Actors' involved in such co-operative R&D projects (in most micro-networks competitive manufacturers) did not intend to commercialise the technology. Stimulating co-operation was most effective in pre-competitive R&D; at this stage, actors' stake was to learn in interaction with other competent actors. The value of stimulating or insisting on co-operation depended on the stage of a technology's development and on the mutual interests and stakes of the participating actors.

## 8.8. Increasing the effect of government intervention?

The insights generated by comparing the technology case studies lead us to draw four policy-relevant conclusions.

Our first conclusion regarding technological development in the manufacturing industry is that actors are strongly constrained by the existing production process. The existing production process tends towards system optimisation rather than to the complete renewal of the production process. Second, technological development in the manufacturing industry takes considerable time; innovative technologies may slumber for decades; subsequently, it takes at least ten to fifteen years (often longer) before the technology is 'proven' on a commercial scale. Third, effective stimulation of the development of industrial energy-efficient process technologies is not easy. Firms were willing and able to develop the technologies themselves. However, effective intervention occurred too. Our fourth conclusion is that there is considerable variety in the technology networks that develop the energy-efficient technologies. The general promise of innovative industrial energy-efficient technologies masks heterogeneity. There is no 'one size fits all' strategy that can be applied to all energy-efficient process technologies in all manufacturing industries.

These observations link to two important dilemmas regarding the role of government in stimulating technological development. Should government play any role in stimulating the development of such industrial process technologies? And, if so, should government adopt a generic or specific intervention strategy? The societal importance of further improvements in industrial energy efficiency and the somewhat disappointing effect of government intervention in stimulating the development of such technologies so far, make us wonder how the effect of government intervention can be improved.

The diversity between the manufacturing industries and various technology networks calls for government intervention strategies that are better tailored to the networks of a specific industry. National governments should have a thorough knowledge of the (international) technology networks and of the role and capacities of actors that they can address before deciding *if* and *how* to intervene.

We do not intend that stimulating technology development can always be effective. We do neither intend that government should select the innovative process technologies that industries need. However, we do suggest that information about patterns of innovation and international technology networks can provide (qualitative) insight that is valuable for improving the effect of government intervention.

We have the following recommendations and ideas for improving the effect of government intervention directed at technological development in manufacturing industries:

- Government has to consider its access to actors that can play a crucial role in international technology networks within which industrial energy-efficient process technologies are developed. It is also important to know what specific knowledge and R&D experience regarding manufacturing industries and process technologies are available within a country.
- National governments can increase their access to actors by joining forces at an international level. A suggestion is to come to R&D contracts or R&D agreements with actors that can make a difference in the energy-efficiency performance of innovative technologies for the manufacturing industry. One can also think of international R&D programmes. Another international strategy is for international bodies to map the technology networks of major energy-efficient process technologies.
- If government has no direct access to micro-networks, government may deploy indirect intervention strategies. Government can for instance decide to a more stringent policy regarding voluntary agreements on industrial energy efficiency. It can also ensure that a regular information provision is made available about the performance of innovative energy-efficient technologies to the national manufacturing industry (and to themselves).
- The momentum of technology networks gives a first indication whether government should intervene at all. Momentum should not be to low, neither too high. By monitoring how a technology networks' momentum changes governments may be able to support the development of an energy-efficient technology when it is needed.
- Long-term government R&D commitment is required for developing energy-efficient technologies. If the development of an energy-efficient technology has gone on for *more* than 5 years or if actors keep coming back for R&D support and have taken no serious step to up-scale the technology, government has to be cautious about continuing financial R&D support. Government may monitor the changes in the international technology network continuously in order to decide whether to continue R&D support or not.
- The fact that actors' and governments' agendas differ is not a reason for failing to stimulate the development of industrial energy-efficient technologies. However, government has to protect its own agenda. Government should have a thorough insight into energy-efficiency improvements and into the other (more) promising performance characteristics. Claims about energy-efficiency improvements have to be evaluated critically. A supply of external independent information may be important in this regard.
- In stimulating the development of industrial energy-efficient technologies governments need a certain degree of flexibility in designing a tailor-fit strategy. For instance, is not always needed to involve or focus on the energy end-users. In specific cases, it should be possible to support (expensive) demonstration facilities.
- Intervention strategies that affect the demand for technological innovation (such as for instance regulatory and economic instruments) are not likely to initiate the

large R&D efforts needed to develop energy-efficient process technologies. However, such instruments do draw attention to industrial energy efficiency.

- Intervention strategies that initiate networks and require co-operation between different types of actors can be very useful, but also have their shortcomings. The added-value of co-operation and interaction will depend largely on the stage of development, the stakes of the actors and the target group of actors addressed.
- Government has much to gain if it can accelerate the emergence of a robust technology network. It would be interesting to find a way to activate R&D for technologies that are still at the exploration stage. A suggestion would be to stimulate ‘radical variation’ in a protected environment by giving financial support to experienced researchers with a thorough knowledge of the manufacturing process and with experience in commercialising technologies.

To conclude, industrial energy-efficient process technology remains a major opportunity in mitigating greenhouse gas emissions. Government needs thorough insight into both the technical and the social aspects of technological development if its intervention strategies are to be successful. It has to look beyond industrial energy efficiency. It is important to develop strategies that are able to support, strengthen and affect actors and networks and, thereby, lead technological development in the manufacturing industry in less energy-intensive directions.

# Samenvatting

## Introductie

Het intensieve gebruik van fossiele brandstoffen laat een sterke verwevenheid zien tussen technologie en menselijke activiteit. Het winnen, verwerken en verbranden van fossiele brandstoffen is mogelijk dankzij technologieën. We gebruiken fossiele energie onder andere voor de productie van elektriciteit, de warmtevoorziening, en de industriële productie van allerlei goederen. Dit leidt tot milieuproblemen, zoals een versterkte uitstoot van broeikasgassen. Om dit probleem op te lossen, zoekt men naar allerlei innovatieve technologieën. Deze zouden er voor moeten zorgen dat het gebruik van energie in de toekomst op een duurzame manier gebeurt. De opwekking van elektriciteit kan duurzamer door gebruik te maken van bijvoorbeeld zonnecellen en windmolens. Maar ook het eind-gebruik van energie in de industrie kan duurzamer door innovatieve technologieën toe te passen die energie besparen.

In dit proefschrift kijken we naar de ontwikkeling van energie-efficiënte procestechnologieën voor de industrie. Industriële energiebesparing beperkt de emissies van $CO_2$, het belangrijkste broeikasgas. Het leidt ook tot kostenbesparing, omdat minder energie nodig is voor de produktie van een ton papier of een ton staal. Onderzoek en ontwikkeling (O&O) naar energie-efficiënte technologieën voor de industrie is een belangrijk aandachtsgebied van verschillende nationale overheden. Dit alles roept de vraag op hoe de overheid de ontwikkeling van dit soort technologieën kan versnellen.

Er is nog weinig onderzoek gedaan naar het effect van overheidsinterventie op de ontwikkeling van industriële procestechnologieën. Overheidsinterventie is effectief als het daadwerkelijk leidt tot een verlaging van het energiegebruik per ton product.

Het is echter niet gemakkelijk om te bepalen welk deel van de daling in het energiegebruik toegeschreven mag worden aan een specifiek beleidsinstrument. Allereerst moet daarvoor inzicht bestaan in het investeringsgedrag van industriële bedrijven. Als het gaat om de implementatie van *bewezen* energie-efficiënte technologieën dan is er inmiddels een redelijk inzicht in de invloed van beleidsinstrumenten op investeringsgedrag. Wat betreft de ontwikkeling van *innovatieve* technologieën is er nauwelijks inzicht in het investeringsgedrag van actoren. Ten tweede is de ontwikkeling van innovatieve technologieën een onzeker proces. Het kost tijd en allerlei (onverwachte) gebeurtenissen kunnen een rol spelen. Van tevoren is bekend hoe belangrijk een bepaald onderzoek zal zijn en of de technologie ook echt commercieel toegepast gaat worden.

Gegeven deze moeilijkheden, hebben wij ervoor gekozen om een omweg te maken. We beginnen niet met de evaluatie van specifieke beleidsinstrumenten, maar we proberen eerst het inzicht in de ontwikkeling van energie-efficiënte procestechnologieën te vergroten. We kijken naar de rol van actoren en het belang van dynamiek. De omweg bestaat uit het in detail bestuderen van de ontwikkelingstrajecten van energie-efficiënte procestechnologieën. We zullen vier gedetailleerde case-studies uitvoeren.

Het doel van dit proefschrift is het verkrijgen van inzicht in het proces van de ontwikkeling van energie-efficiënte procestechnologieën voor de industrie. We doen dit om te verkennen hoe de overheid de ontwikkeling van dit soort technologieën kan stimuleren.

Het proefschrift kent drie delen. Ten eerste nemen we kennis van de inzichten uit de technologiestudies. Op basis hiervan stellen we een kader voor dat gebruikt kan worden voor de analyse van de vier case-studies. Het kader karakteriseert het ontwikkelingstraject van een technologie in termen van actoren (waaronder de overheid) en netwerken. In het tweede deel komen de ontwikkelingstrajecten van vier specifieke procestechnologieën aan bod. Een belangrijk deel van het proefschrift bestaat uit deze empirische analyse. We hebben vier – vaak door energie-analisten genoemde – innovatieve energie-efficiënte technologieën geselecteerd; twee voor de papierindustrie en twee voor de ijzer- en staalindustrie. Op deze manier hebben we geprobeerd een balans te vinden in de mate van overeenkomst en variëteit tussen de vier case-studies. Voor elke case-study evalueren we de rol en het effect van overheidsinterventie. In het derde deel worden de vier case-studies vergeleken en wordt verkend wat de mogelijkheden zijn voor de overheid om de ontwikkeling van dit soort technologieën zo effectief mogelijk te stimuleren.

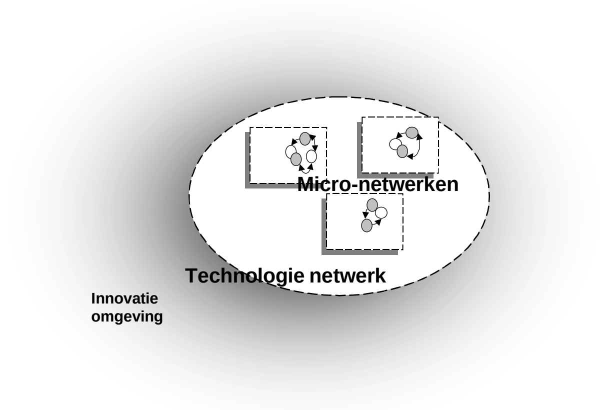
## Kader voor de empirische case-studies

In hoofdstuk 2 is een kader ontwikkeld dat houvast geeft bij het uitvoeren en de analyse van de vier case-studies. We hebben gekeken naar de verschillende theoretische benaderingen binnen technologiestudies. Voor elke benadering zijn de belangrijkste concepten bestudeerd en is een samenvatting gemaakt op basis van drie aandachtspunten:

- Hoe kijkt de benadering tegen technologie-ontwikkeling aan?
- Wat beïnvloedt de richting van technologie-ontwikkeling?
- Welke mogelijkheden zijn er voor overheidsinterventie?

De benaderingen in technologiestudies verschillen in specifieke uitgangspunten. Ze leggen verschillende accenten. Toch zijn de inzichten in belangrijke mate

complementair. Alle benaderingen zien technologische ontwikkeling als een sociaal proces waarin ‘actoren’, ‘artefacten’ en een ‘agenda’ geconstrueerd worden en interacteren. Actoren moeten het belang zien van (onzekere) investeringen in O&O. Technologische verandering en innovatie is het resultaat van hun activiteiten. Meestal innoveren actoren niet alleen. Andere actoren brengen financiële middelen in, hebben specifieke kennis of bepaalde onderzoeksapparatuur, of vormen een toegang tot de markt. De overheid is een van de actoren die een rol kan spelen. Het concept ‘netwerk’ is een sleutelbegrip geworden. De richting van technologie-ontwikkeling wordt bepaald door de keuzes van actoren. In het maken van deze keuzes worden actoren geleid door de omgeving waarin zij opereren. Eerdere O&O of eerdere (succesvolle) ervaringen met het ontwikkelen van technologie, de wensen van de toepasser van de technologie, de markt waarin de producent opereert en de reeds in gebruik zijnde procestechnologieën zorgen ervoor dat actoren in een bepaalde richting zoeken. Op deze manier wordt de onzekerheid in investeringen in O&O zo veel mogelijk beperkt.
Figuur 1 visualiseert het kader dat gebruikt wordt voor de analyse van de vier case-studies. Het kader karakteriseert het ontwikkelingstraject van een technologie in termen van ‘actoren’ (waaronder de overheid), ‘artefacten’ en ‘agenda’. Het structureert onze zoektocht naar wie betrokken is, wie met wie samenwerkt en tussen wie kennis en informatie wordt uitgewisseld – actoren –. Het dwingt ons te begrijpen waarom actoren voorkeuren hebben voor een bepaalde richting van technologie-ontwikkeling – agenda –. En tenslotte worden de resultaten en opschalingstappen van O&O in kaart gebracht en wordt bekeken hoe dit de verdere ontwikkeling van de technologie heeft beïnvloed – artefact –.




*Figuur 1: Het kader dat gebruikt wordt om het ontwikkelingstraject van innovatieve energie-efficiënte procestechnologieën te analyseren.*

Het artefact <u>materialiseert</u> binnen een <u>micro-network</u>, dat vaak bestaat uit een of een paar actoren. Het <u>technologie-netwerk</u> omvat alle micro-netwerken die dezelfde procestechnologie ontwikkelen. De actoren liggen ingebed in een context, de

innovatie omgeving. Deze omgeving beïnvloedt de ideeën en voorkeuren van actoren.
We hebben vragen geformuleerd over de micro-netwerken, het technologie-netwerk en de materialisatie van de technologie. Deze worden gebruikt bij de uitvoering en analyse van de vier case-studies. Tenslotte wordt voor elke case-study het effect van overheidsinterventie geëvalueerd. Op basis van het verkregen inzicht in het netwerk van actoren, kunnen we aangeven hoe belangrijk overheidsinterventie is geweest. Het is belangrijk om aan te geven wat we verstaan onder 'effect'. We onderscheiden drie deel-aspecten:

- Additionaliteit – Overheidsinterventie is additioneel als het leidt tot activiteiten binnen een micro-netwerk die niet gestart of gecontinueerd zouden zijn zonder interventie.
- Versnelling – Overheidsinterventie versnelt technologie-ontwikkeling wanneer interventie er toe geleidt dat de materialisatie en opschaling van de technologie binnen het technologie-netwerk sneller is gegaan, dan zonder interventie het geval zou zijn geweest.
- Effectiviteit – Overheidsinterventie is effectief wanneer een innovatieve procestechnologie daadwerkelijk tot energiebesparing leidt.

## De schoenpers

In hoofdstuk 3 is het ontwikkelingstraject van de schoenpers geanalyseerd. De schoenpers is een technologie voor de perspartij van een karton- of papiermachine. De schoenpers vergroot de hoeveelheid water die mechanisch uit het papier wordt verwijderd. Hierdoor hoeft er in de droogpartij van een karton- of papiermachine minder water verdampt te worden. Dit bespaart energie. In 1980 is deze technologie voor de eerste keer op commerciële schaal toegepast. De schoenpers is een van de belangrijkste innovaties geweest in de papierindustrie in de 20ste eeuw. In deze case-study is specifiek gekeken naar het belang van kenmerken van de actoren en van externe factoren op de ontwikkeling en diffusie van de schoenpers.
Het technologie-netwerk van de schoenpers is tijdens de ontwikkeling erg klein geweest (1967 -1980). Er was slechts één micro-netwerk actief. Voor lange tijd bestond het micro-netwerk slechts uit één actor, de Amerikaanse machinebouwer Beloit. Buiten dit micro-netwerk waren er onderzoekers die het belang van het idee achter de schoenpers inzagen. Vanaf 1960 werd er meer basisonderzoek gedaan naar het verwijderen van water in de pers. Hierdoor was duidelijk geworden dat de verblijftijd van het papier in de pers een belangrijke factor is. De schoenpers maakt hier gebruik van door het contactmoment tussen pers en papier te verlengen. Zo wordt meer water verwijderd. Ook al erkenden anderen het belang van de factor tijd, alleen Beloit investeerde in de ontwikkeling van de schoenpers. Alleen de onderzoekers en technici van Beloit bleven er in geloven dat dit nieuwe type pers daadwerkelijk gebouwd kon worden. Het ontwerp van de schoenpers was een breuk

met de tot dan toe gebruikte rolpersen. Een van de twee stalen rollen zou vervangen worden door een ‘flexibel’ materiaal waardoor het contactoppervlak met de andere rol en het papier vergroot zou worden. Velen geloofden niet dat het mogelijk was om zo’n flexibel materiaal te gebruiken.
Ook binnen Beloit liep de ontwikkeling niet altijd even gemakkelijk. Een viertal mensen is van belang geweest om de ontwikkeling gedurende 13 jaar gaande te houden. Op basis van hun eerdere ervaringen in O&O en met het naar de markt brengen van nieuwe technologieën, hun creatieve ideeën om bepaalde problemen op te lossen, en hun overtuiging dat de schoenpers zeer interessant was voor kartonproducenten, hield men vertrouwen dat een werkende schoenpers gebouwd moest kunnen worden. Er zijn talloze ontwerpen voor mogelijke persen gemaakt. Het aantal patenten van Beloit voor mogelijke schoenpersen is groot.
Pas tegen de tijd dat Beloit een schoenpers op een van de pilot-papiermachines ingebouwd had, raakten er andere actoren betrokken. Weyerhaeuser, een van Amerika’s grootste kartonproducenten (en een van Beloit’s belangrijkste klanten) had reeds in 1973-74 belangstelling getoond voor de schoenpers. In 1978 raakte zij definitief betrokken. In Juni 1979 besloot Weyerhaeuser om een eerste schoenpers te kopen. Opvallend genoeg hadden Beloit en Weyerhaeuser op dat moment nog geen definitieve oplossing voor het flexibele materiaal dat nodig was om de pers operationeel te krijgen. Beloit benaderde een toeleverancier van machinebekleding, Albany. Zij moesten het probleem maar definitief oplossen. Albany kwam met de suggestie een poly-urethaan gecoate belt te gebruiken. In december 1980 werd de eerste schoenpers bij Weyerhaeuser opgestart. De pers werd ingebouwd op een bestaande kartonmachine. Mede dankzij de poly-urethaan gecoate belt draaide de pers vanaf het eerste moment naar grote tevredenheid. Zonder dit materiaal zou de innovatie van de schoenpers – tenminste – een aantal jaar vertraagd zijn.
Beloit’s belangrijkste drijfveer om de schoenpers te ontwikkelen was dat dit de ontwatering in de perspartij zou verbeteren. Bij een bestaande kartonmachine kan dan de productie verhoogd worden. Voor een compleet nieuwe kartonmachine gaan de investeringskosten omlaag. Weyerhaeuser was ook geïnteresseerd in de verbeterde sterkte-eigenschappen van het karton (wat weer leidt tot een vermindering van grondstofkosten).
Andere internationale machinebouwers begonnen pas omstreeks 1980 met de ontwikkeling van een schoenpers. Niet alleen machinebouwers, maar ook toeleveranciers van machinebekleding richtten zich op deze groeiende markt. Drie machinebouwers introduceerden een concurrerend ontwerp. Voith (Duitsland) introduceerde zijn eerste schoenpers in 1984, Escher Wyss (Duitsland) in 1986 en Valmet (Finland) in 1990. Er zijn dus in totaal vier machinebouwers geweest die schoenpersen verkochten. In 2001, zijn er nog twee over. De twee Duitse machinebouwers zijn gefuseerd en het Amerikaanse Beloit is failliet.
Beloit’s concurrenten slaagden er in een verbeterd ontwerp van de schoenpers op de markt te brengen. Zij kozen voor een zogenaamde ‘gesloten’-schoenpers in plaats van de ‘open’-schoenpers van Beloit. In een gesloten-schoenpers is de olie in de pers geïsoleerd van de papierbaan. De kans op vervuiling van het papier (zeker bij hogere

snelheden) wordt hierdoor kleiner. Deze keuze bleek van groot belang te zijn. Zowel karton- als papiermakers streven namelijk naar een voortdurende verhoging van de snelheid van hun machines. De vraag is waarom Beloit dan toch in eerste instantie een open-schoenpers op de markt heeft gebracht? Zij kende immers de voorkeur van de markt voor het verder vergroten van de snelheid (dat was immers de reden om de pers in eerste instantie te ontwikkelen). Ten eerste wilde Beloit na 13 jaar ontwikkeling de schoenpers zo snel mogelijk op de markt brengen. Ten tweede hangt het ontwerp van de schoenpers sterk samen met het flexibele materiaal, de belt. Dit was tot het laatste moment een probleem voor Beloit. Het was makkelijker om een belt te produceren voor een open-schoenpers dan voor een gesloten-schoenpers. Nog los van het feit dat Beloit de tijd niet wilde nemen om een verbeterd productieproces voor deze belts te ontwikkelen, merkte een van de betrokken experts van Beloit op: “we moesten nu eenmaal kunnen lopen voordat we konden leren rennen”.
Zowel machinebouwers als toeleveranciers van machinekleding vervolgden hun onderzoekswerkzaamheden. De pers zelf, maar ook complementaire technologieën als vilten en belten, werden verbeterd. Ook gebruikten de machinebouwers hun pilot-papiermachines om andere producenten dan kartonproducenten te overtuigen van het voordeel van de schoenpers. Gedurende de jaren tachtig werd de schoenpers alleen toegepast voor de productie van karton. Het duurde tot 1994 voordat Voith de eerste schoenpers op een (bestaande) papiermachine installeerde. Technologische verbeteringen waren belangrijk om de schoenpers geïntroduceerd te krijgen (heel belangrijk was de configuratie van de schoenpers in de totale perspartij). Nog belangrijker was echter dat de ontwatering in bestaande perspartijen een knelpunt werd. De snelheid van bestaande papiermachines kon niet verder verhoogd worden met rolpersen. Pas toen durfden papierproducenten het aan om de stap naar de schoenpers te maken. Door een schoenpers in te bouwen werd de ontwatering verbeterd en kon de machinesnelheid weer verder toenemen.
De overheid heeft geen bijdrage geleverd aan de ontwikkeling van de schoenpers. Toen het moment van innovatie dicht bij kwam, heeft Beloit wel aan de Amerikaanse overheid gevraagd om het risico van innovatie financieel af te dekken. In deze poging benadrukte Beloit de energiebesparingsmogelijkheden van de schoenpers. De Amerikaanse overheid had hier op zich wel oren naar, maar was te traag in het honoreren van Beloit’s voorstel. De rol van de overheid zou echter weinig effect gehad hebben. Ook zonder overheidsinterventie slaagde Beloit er in om de technologie geïntroduceerd te krijgen.
Een belangrijke conclusie van deze case-study is dat actor-kenmerken – Beloit’s kennis, ervaring en vertrouwen dat een schoenpers echt gebouwd kon worden – van doorslaggevend belang zijn geweest voor de succesvolle introductie van de schoenpers in 1980. Hierbij dienen wel wat kanttekeningen gemaakt te worden. Meer onderzoekers zagen het belang in van de factor tijd in de perspartij. Beloit had een grondige kennis van de markt en de marktwensen van karton- en papiermakers. En tenslotte was Beloit een van de internationaal vooraanstaande machinebouwers. Een tweede conclusie is dat externe factoren – het succes van de schoenpers in de markt

en de voorkeuren van de toepassers van de technologie – bepalend waren voor de verdere ontwikkeling van de technologie na 1980.

## Impulstechnologie

In hoofdstuk 4 is het ontwikkelingstraject van impulstechnologie geanalyseerd. Impulstechnologie is net als de schoenpers een perstechnologie voor de productie van karton en papier. Eigenlijk is impulstechnologie een schoenpers (eerst werden ook conventionele rolpersen gebruikt), die verwarmd wordt (meestal door elektriciteit). De combinatie van druk en warmte leidt tot extra ontwatering. In deze case-study is gekeken naar het effect van financiële bijdrage van de overheid op de ontwikkeling van de technologie.
Het technologie-netwerk (1980-2000) van impulstechnologie bestond uit twee micro-netwerken, één in Noord-Amerika en één in Zweden/Finland. Momenteel is alleen het Scandinavische micro-netwerk nog actief.
Voordat het technologienetwerk echt van de grond kwam voerde de Zweed Douglas Wahren onderzoek uit naar impulstechnologie. Wahren is de bedenker van de technologie. Hij stelde voor om de ontwatering in de pers te intensiveren met behulp van warmte. Tussen 1970 en 1980 werkte hij op twee verschillende werkplekken aan zijn idee. Twee keer stopte hij echter met zijn onderzoeksactiviteiten. Eerst was hij werkzaam bij het Zweedse nationale papieronderzoeksinstituut STFI. Daar had hij niet de capaciteit om het onderzoek uit te voeren (1972-1973). Als medewerker van de Zweedse machinebouwer KMW bouwde hij impulstechnologie in op een pilot-papiermachine (1977). Ook vroeg hij een patent aan. Maar toen bleek dat de eigenschappen van het papier niet overeenkwamen met de eigenschappen van het papier dat gemaakt werd op de papiermachines die KMW verkocht stopte hij voor de tweede keer zijn onderzoek.
Eind jaren zeventig werd Wahren gevraagd om het onderzoek bij het Amerikaanse papieronderzoeksinstituut IPST te reorganiseren. Bij IPST kreeg hij, met instemming van de rest van het bestuur, de ruimte om de ontwikkeling van impulstechnologie opnieuw op te pakken. Op basis van wat eerste metingen claimde Wahren in 1983 een compleet nieuw ontwateringsprincipe door de combinatie van druk en warmte. Al eerder benaderde Wahren wat oude bekenden bij de Amerikaanse machinebouwer Beloit. Na hun succes met de schoenpers waren ze geïnteresseerd om de ontwatering in de pers verder te verbeteren. Beloit startte in 1981 eigen onderzoek. IPST benaderde ook de Amerikaanse overheid, het ministerie van Energie, en vroeg om een financiële bijdrage voor het onderzoek. Op basis van de verwachting dat impulstechnologie de ontwatering in de perspartij zou verbeteren claimde IPST energiebesparing. De mogelijkheid van energiebesparing, het risicovolle karakter van de technologie en de mogelijkheid om de concurrentiepositie van de Amerikaanse papierindustrie te verbeteren waren redenen voor het ministerie van Energie om gedurende lange tijd het onderzoek bij IPST te steunen (1985-1999). Ook de vice-

president van het Canadese papieronderzoeksinstituut Paprican was gecharmeerd door het ontwateringsprincipe van impulstechnologie. Omstreeks 1986 besloten de Canadezen impulstechnologie op hun pilot-papiermachine in te bouwen. In deze fase werkten ook de Canadezen samen met Beloit. Net als haar Amerikaanse zusterinstituut ontving Paprican geld van de nationale overheid. Ook hier was een verbetering in energie-efficiëntie een belangrijk argument voor het verstrekken van een bijdrage. De twee onderzoeksinstituten binnen het Noord-Amerikaanse micro-netwerk verdeelden de taken. De activiteiten bij IPST richtten zich vanaf 1989 op karton, terwijl Paprican het impulspersen van krantenpapier bestudeerde. Karton is een belangrijk product voor de Amerikaanse papierindustrie, terwijl krantenpapier belangrijk is voor de Canadese papierindustrie.
In totaal zijn in dit Noord-Amerikaanse micro-netwerk 4 pogingen ondernomen om de technologie te commercialiseren. Geen van deze pogingen is geslaagd. Tussen 1987 en 1989 werd de eerste poging ondernomen door IPST, Beloit en het Amerikaanse Weyerhaeuser, het kartonbedrijf dat ook al de stap waagde om de eerste schoenpers neer te zetten. De drie actoren hadden het vertrouwen dat ze een grote stap konden maken in het commercialiseren van impulstechnologie. Er waren al eerder wat aanwijzingen geweest dat het papier zichtbaar beschadigde door de combinatie van druk en warmte, maar de testen op de pilot-papiermachine van Beloit maakten pas echt duidelijk dat delaminatie een groot probleem was. De vezels raakten zichtbaar beschadigd. De samenwerking tussen IPST en Beloit stopte formeel. Weyerhaeuser zag af van verdere betrokkenheid.
Vanaf 1992 claimden de onderzoekers van IPST dat het delaminatie-probleem voor karton opgelost was. De samenwerking met Beloit werd aangehaald, mede omdat IPST zelf geen pilot-papiermachine had. IPST wilde opnieuw impulstechnologie commercieel toepassen. Het ministerie van Energie wilde wel betalen, mits er een machinebouwer en een kartonproducent betrokken werden. Ook Beloit wilde wel, maar IPST kon geen van de Amerikaanse kartonfabrikanten overtuigen van de voordelen van impulstechnologie. Niemand wilde de eerste zijn. IPST en Beloit kregen uiteindelijk toch geld van de overheid om impulstechnologie in te bouwen op de nieuwe pilot-papiermachine van Beloit. Bij Beloit was de interne steun inmiddels afgenomen, maar mede door de bijdrage van de overheid kon dit experiment toch uitgevoerd worden.
Nadat Paprican het onderzoek had afgerond, probeerde Paprican en Beloit omstreeks 1994-95 een krantenproducent te vinden om impulstechnologie commercieel toe te passen. Op dat moment was de schoenpers nog geen bewezen technologie voor krantenpapier. De stap naar twee schoenpersen (wat nodig was in verband met papiereigenschappen), die ook nog eens verwarmd zouden worden, was te onzeker en te groot.
IPST en Beloit kwamen eind jaren negentig tot een vierde poging. Inmiddels waren ze er bij IPST achter gekomen dat het delaminatie-probleem voor karton nog niet was opgelost. Nieuwe oplossingen werden ontwikkeld, gepatenteerd en ingebouwd op de pilot-papiermachine van Beloit. Weer lukte het niet om een kartonproducent te vinden voor een eerste commerciële toepassing. De eigenschappen van het karton

verbeterde wel, maar niet genoeg om het kostennadeel van de dure elektriciteit te compenseren. IPST stopte het onderzoek. De taken waren afgerond. Ook Beloit moest stoppen, doordat het moederbedrijf failliet is gegaan.

Toen eind jaren tachtig onderzoeksresultaten uit Noord-Amerika beschikbaar kwamen raakten ook actoren in Europa geïnteresseerd in impulstechnologie. Een vertegenwoordiger van de Zweedse overheid bood het papieronderzoeksinstituut STFI een financiële bijdrage aan wanneer zij onderzoek naar deze ‘energie-efficiënte en risicovolle’ technologie zouden opstarten. Na zes tot zeven jaar van onderhandeling, en bespreking, en planvorming en verdere onderhandelingen werd uiteindelijk de pilot-papiermachine van STFI omgebouwd met twee schoenpersen. In 1997 kon het grootscheeps aangekondigde onderzoeksprogramma naar impulstechnologie beginnen. De Finse machinebouwer Valmet is betrokken. Pas nadat het onderzoek bij STFI (2002) is afgerond bepalen de Finnen of ze verder inzetten op impulstechnologie. De technologie moet concurreren met andere innovatieve pers- en droogtechnologieën, die Valmet heeft ontwikkeld.

Twee andere papiermachinebouwers hebben onderzoek naar impulstechnologie nooit op pilot-schaal voortgezet. Impulstechnologie kwam weer even ter sprake toen de bedrijven fuseerden, maar men ziet geen toekomst voor de technologie.

Wahren’s oorspronkelijke reden om naar een verbeterde ontwatering in de perspartij te zoeken was dat hij de kapitaalslasten van de papierproductie wilde reduceren. Net als in het geval van de schoenpers belooft impulstechnologie een verhoging van de machinesnelheid voor bestaande machines en een lagere investering voor nieuwe papiermachines. Deze overwegingen waren voor alle actoren de belangrijkste reden om de technologie te ontwikkelen. De mogelijke verbetering in energie-efficiëntie was het belangrijkste argument om geld van de overheid te krijgen. Zowel de Amerikaanse, de Canadese als de Zweedse overheid hebben aanzienlijke financiële bijdragen verstrekt aan de nationale papieronderzoeksinstituten.

Vijfentwintig jaar onderzoek en vijftien jaar steun door de overheid hebben nog niet geleid tot commerciële toepassing van de technologie. Wahren claimde in 1983 een enorme verbetering van de ontwatering. Deze claim is in de loop van de tijd kleiner geworden. Bovendien is er nog steeds discussie over het door hem voorgestelde ontwateringsprincipe. De hoeveelheid energie die impulstechnologie mogelijk kan besparen staat nog niet vast. Verhitting met behulp van elektriciteit is energetisch niet gunstig. De toekomst van de technologie is al met al onzeker. De kansen voor commercialisering – in zijn huidige ontwerp met de lengte van de huidige schoenpersen – wordt door sommigen betwijfeld.

Een eerste conclusie van deze case-study is dat de bijdragen van de overheid de ontwikkeling van impulstechnologie hebben versneld. Zonder het geld van de overheid zouden IPST en Paprican geen pilot-papiermachine onderzoek hebben kunnen doen. Zonder het werk door IPST en Paprican zou het onderzoek bij Beloit eerder gestopt zijn. Zonder het Zweedse overheidsgeld zou er nu geen Scandinavisch micro-netwerk zijn. Maar ook al heeft de subsidiëring geleid tot een versnelling van de ontwikkeling, de technologie is nog altijd niet bewezen en het effect in termen van energiebesparing is nog onzeker.

Een tweede conclusie is dat de intenties en strategieën van de onderzoeksinstituten in grote mate bepalend zijn geweest voor het onderzoek. Dit is op zich niet erg. Deze actoren hebben immers een goede kennis van de technologie en van de wensen van de papierindustrie. Maar de instituten zijn afhankelijk van overheidsgeld voor de continuering van onderzoek en de verbetering van bijvoorbeeld pilot-papiermachines. Het gevaar dreigt dat het krijgen van geld een doel op zich wordt; het ontwikkelen van een commercieel toepasbare technologie is dan van ondergeschikt belang.

## Strip-casting technologie

In hoofdstuk 5 is het ontwikkelingstraject van strip casting technologie geanalyseerd. Strip-casting technologie integreert het gieten en walsen van staal. Hierdoor is herverhitten van staal tussen deze twee processtappen niet langer nodig en wordt energie bespaard. Strip-casting is de derde technologie in een serie van innovatieve giet-technologieën die er voor zorgen dat vloeibaar staal steeds dunner uitgegoten kan worden. Na de introductie van continu-gieten in 1952 en thin-slab-casting technologie in 1989 staat strip-casting technologie op het punt om commercieel toegepast te gaan worden. In deze case-study is met name gekeken naar het effect van financiële bijdrage van de overheid op de ontwikkeling van de technologie.
Het technologie-netwerk rond strip-casting technologie is pas sinds 1980 echt van de grond gekomen. Het idee voor strip-casting is al veel ouder. Bessemer, een van de ‘klassieke’ innovatoren binnen de staal industrie, had in 1857 al een patent voor strip-casting op zijn naam staan. Er is vanaf dat moment door verschillende actoren onderzoek gedaan naar strip-casting technologie, maar het duurde dus tot 1980 voordat O&O naar strip-casting technologie echt een vlucht nam. Het technologie-netwerk heeft bestaan uit elf micro-netwerken. Alle micro-netwerken bestonden uit een staalbedrijf en een machinebouwer of engineering bedrijf. De staalbedrijven waren of grote geïntegreerde staalbedrijven met een roestvrij staal-divisie, of gespecialiseerde roestvrij-staalbedrijven. In bijna alle micro-netwerken lag het initiatief bij de staalproducent. Zij hebben ook bijna altijd de rechten op belangrijke patenten.
Momenteel zijn nog zes van de elf micro-netwerken actief. Vier micro-netwerken hebben hun O&O gestopt. Twee micro-netwerken zijn samengegaan door een fusie van staalbedrijven. Drie van de micro-netwerken die nog actief zijn hebben een strip-caster operationeel op industriële schaal. Ze hebben alle drie ongeveer 15 jaar nodig gehad om dit te bereiken. De verwachting is dat deze drie micro-netwerken binnen twee tot drie jaar de haalbaarheid van de technologie bewijzen; de rest van de staalindustrie wacht dit af.
De belangrijkste reden om strip-casting technologie te ontwikkelen is de reductie van de kapitaallasten voor warm-walsen. Een walserij is duur en kan alleen uit bij een grote capaciteit. Roestvrij-staalproducenten, die relatief klein zijn, besteden het

warm-walsen van staal dan ook uit. Met het beschikbaar komen van strip-casting technologie zouden zij echter zelf het staal in de gewenste dikte kunnen gieten. Doordat een strip-caster het vloeibare staal dunner uitgiet is de warme wals niet langer nodig.

Bessemer was zich al bewust van het enorme kapitaalvoordeel van strip-casting technologie. Hij zag dat het geweldig zou zijn om vloeibaar staal in één keer dun uit te gieten. Toch heeft het meer dan een eeuw geduurd voor dat de ontwikkeling van strip-casting technologie echt op gang kwam. Verschillende gebeurtenissen en ontwikkelingen waren nodig om onderzoek naar strip-casting stevig op de O&O agenda te krijgen. De introductie van continu-gieten (1952) was een eerste stap om vloeibaar staal uit te gieten. Tijdens de jaren zestig en zeventig werd deze technologie verder ontwikkeld en breder toegepast. De afgevlakte vraag naar staal na de jaren zeventig vergrootte de interesse voor technologieën die verschillende processtappen zouden kunnen integreren. Verder was de basiskennis op het gebied van solidificatie van staal, ceramische materialen en procesautomatisering beschikbaar gekomen. Tenslotte groeide de productie van nieuwe staalsoorten zoals roestvrij staal en zette de opmars van de zogenaamde mini-mill staalbedrijven door. De productiecapaciteit van deze bedrijven is kleiner en dus hebben zij belang bij strip-casting technologie. Al met al begonnen staalbedrijven tussen grofweg 1975 en 1985 te zoeken naar compactere giet-processen. Ook het idee van Bessemer om twee rollen te gebruiken werd weer opgepakt. Allerlei relatief kleinschalige onderzoeksprojecten werden opgestart. De resultaten stimuleerden ook andere bedrijven om onderzoek op te pakken. De claim van een Amerikaans roestvrij-staalproducent, dat zij op pilot-schaal konden strip-casten, speelde een belangrijke rol. De bedrijven hadden wel geld voor onderzoek. Er was ook wat geld van de overheid. De aandacht voor deze technologie werd versterkt en het technologie-netwerk groeide.

Verschillende nationale overheden en de Europese Gemeenschap voor Kolen en Staal (EGKS) hebben onderzoek gesubsidieerd. Sinds 1980 hebben zij ongeveer 5 tot 10% van de totale uitgaven door de elf micro-netwerken betaald. Zes van de elf micro-netwerken hebben extern geld ontvangen. In drie van deze micro-netwerken bedroeg de externe bijdrage meer dan 40% van de totale uitgaven binnen dat micro-netwerk. Twee van deze drie micro-netwerken zijn inmiddels gestopt. De derde is nog altijd actief, maar continueert zijn activiteiten bewust op relatief kleine schaal. De drie micro-netwerken, die een strip-caster op industriële schaal hebben, hebben alle drie geen – of bijna geen – externe bijdragen gehad.

De belangrijkste conclusie van deze case-study is dat het effect van externe subsidiëring van O&O van marginaal belang is geweest. De ontwikkeling van strip-casting technologie had, nadat deze eenmaal op gang gekomen was, een enorme vaart van zichzelf. Strip-casting technologie grijpt in op de kern van het proces om staal te maken. De verbetering van energie-efficiëntie en de beschikbaarheid van extern geld speelden slechts een beperkte rol in de ontwikkeling van deze technologie.

## Smeltreductie-technologie

In hoofdstuk 6 is het ontwikkelingstraject van smeltreductie-technologie geanalyseerd. De eerste stap in het maken van staal is het produceren van ruw ijzer. Al eeuwen lang worden hoogovens gebruikt om ijzererts met behulp van cokes te reduceren. Steenkool wordt in coke-ovens voorbewerkt tot cokes. Smeltreductie-technologie is een van de zeer weinige innovatieve alternatieven voor de hoogoven. De technologie belooft niet alleen minder energie-intensief te zijn, het integreert ook verschillende processtappen. Het maken van cokes is niet langer nodig, omdat in smeltreductie-technologie kolen direct gebruikt kunnen worden. In deze case-study is gekeken naar het effect van verschillende manieren van overheidsinterventie op de ontwikkeling van smeltreductie-technologie.

In smeltreductie-technologie wordt steenkool in een bad van vloeibaar ijzer vergast. De chemische energie in het geproduceerde koolmonoxide wordt gebruikt voor de reductie van het ijzererts, maar ook voor het smelten van het erts. Dit principe is al bekend sinds het einde van de dertiger jaren in de twintigste eeuw. Vanaf 1975 is er langzamerhand een technologie-netwerk van de grond gekomen. Toen werd allereerst duidelijk dat een andere nieuwe technologie om ijzer te reduceren niet altijd een economisch haalbaar alternatief was voor de conventionele hoogoven. Daarbij werd de druk om te zoeken naar nieuwe processen om ijzer te maken groter. Vele geïntegreerde staalbedrijven zouden namelijk in het begin van de 21ste eeuw hun coke-ovens moeten vervangen.

Dit stimuleerde de zoektocht naar een innovatieve technologie. De belangrijkste drijfveer was het produceren van ijzer tegen lage kosten. Smeltreductie-technologie zou niet alleen investeringslasten omlaag brengen, ook zou het verwerking van goedkope, niet-metallurgische kolen mogelijk maken. Deze twee factoren beloofden een groot kostenvoordeel. Verder zou het proces energie-efficiënter zijn. En zouden investeringen in milieu-technologieën vermeden kunnen worden, omdat smeltreductie-technologie veel minder schadelijke emissies geeft dan de conventionele coke-ovens en hoogovens. Het kostenvoordeel van alleen de laatste twee factoren zou echter nooit groot genoeg geweest zijn om de ontwikkeling van smeltreductie-technologie te beginnen.

Omstreeks 1975 zijn er vijftien tot twintig projecten opgestart. In de projecten probeerden de onderzoekers tot een hoge graad van voor-reductie te komen. De meeste van deze vroege projecten zijn niet verder gekomen dan onderzoek op pilot-schaal. Eén van deze vroege projecten is wèl op commerciële schaal geïntroduceerd. Dit is het Corex proces van de Oostenrijkse machinebouwer Voest Alpine. Dit is momenteel nog altijd het enige smeltreductie-proces dat commercieel wordt toegepast. Het bleek echter gunstig te zijn om genoegen te nemen met een lagere graad van voor-reductie. De zogenoemde tweede-generatie smeltreductie-processen werden steeds vaker bestudeerd. Sommigen van de vroege projecten evolueerden in micro-netwerken, die dit soort tweede-generatie smeltreductie-processen bestudeerden. Dit was bijvoorbeeld het geval in het Japanse micro-netwerk en het

Nederlands-Britse micro-netwerk. In totaal konden begin jaren negentig negen micro-netwerken onderscheiden worden (inclusief het micro-netwerk van de Oostenrijkse machinebouwer Voest Alpine).
Het technologie-netwerk van smeltreductie-technologie is heterogeen in vergelijking met de drie eerdere technologie-netwerken. Geïntegreerde staalbedrijven namen het initiatief in vier van de negen micro-netwerken. Machinebouwers of engineering bedrijven trokken drie micro-netwerken. Mijnbouwbedrijven speelden een belangrijke rol in twee micro-netwerken. Tenslotte werd het Russische micro-netwerk geïnitieerd door de Russische overheid en een Russisch kennisinstituut. Er bestaan technisch aanzienlijke verschillen tussen de smeltreductie-processen van de verschillende micro-netwerken. De technische voorkeuren hingen sterk samen met de eerdere onderzoeks- en engineeringervaring van de actoren. Verschillende actoren hebben het ontwerp van een al bestaand proces geprobeerd geschikt te maken voor de reductie van ijzer. Met name de geïntegreerde staalbedrijven hebben voortgeborduurd op de ervaringen met het toevoegen van kolen en schroot in het proces om staal te maken.
Van de negen micro-netwerken zijn er momenteel nog zes actief. De drie micro-netwerken die gestopt zijn, werden alle drie gedomineerd door geïntegreerde staalbedrijven. Deze bedrijven hebben hun directe belangstelling voor smeltreductie-technologie echter in de loop van de tijd verloren. Ze zijn er tussentijds in geslaagd om de levensduur van de bestaande coke-ovens te verlengen. De meeste bedrijven gebruiken inmiddels minder cokes, omdat ze geïnvesteerd hebben in koleninjectie in de hoogovens. Daarbij hebben ze tevens de productiviteit van de faciliteiten vergroot. De verbeteringen in de bestaande processen zijn zo groot geweest, dat het oorspronkelijk verwachte kostenvoordeel van smeltreductie-technologie in de loop van de tijd is afgenomen. Verder heeft geen van de betrokken geïntegreerde staalbedrijven op het moment behoefte aan een vergroting van ijzer-productie capaciteit. De verdere ontwikkeling en introductie van smeltreductie-technologie door geïntegreerde staalbedrijven is ‘uitgesloten’ (locked-out) door geleidelijke verbeteringen in de bestaande productieprocessen.
Ondanks het feit dat veel geïntegreerde staalbedrijven hun interesse verloren, is de toekomst van smeltreductie-technologie nog open. Mijnbouwbedrijven zijn nog altijd geïnteresseerd. Verder is de rol van mini-mill staalbedrijven in het technologie-netwerk toegenomen. Mini-mills verwerken normaal gesproken schroot, maar ze hebben interesse voor hoogwaardigere grondstoffen. Ze kunnen dan namelijk hoogwaardige staalproducten leveren. De productiecapaciteit van dit soort bedrijven is kleiner dan van de geïntegreerde staalbedrijven. Smeltreductie-technologie is echter een relatief kleinschalig proces. Het toepassen van smeltreductie-technologie voor een mini-mill garandeert een kwalitatief hoogwaardige grondstof. Dit is een mogelijke ‘niche’ toepassing voor smeltreductie-technologie. Wanneer smeltreductie de verwerking van schroot verdringt, zal de energie-intensiteit van deze productieroute toenemen.
Op verschillende manieren hebben nationale overheden geprobeerd de ontwikkeling van smeltreductie te beïnvloeden. Ten eerste hebben nationale overheden en de

Europese Gemeenschap voor Kolen en Staal (EGKS) onderzoek naar smeltreductie-technologie gesubsidieerd. Ongeveer 20 tot 25% van de totale investering in alle negen micro-netwerken tezamen is verstrekt door externe bronnen. In acht van de negen micro-netwerken is er sprake geweest van een bijdrage door derden. In drie micro-netwerken kwam meer dan 40% van het budget van buiten. Het is opvallend dat 90% van de totale bijdrage door overheden en de EGKS (in totaal ongeveer 165 miljoen dollar) besteed is in deze drie micro-netwerken. Ten tweede hebben de geldverstrekkers eisen gesteld aan samenwerking in juist deze drie micro-netwerken. Zowel het Japanse als het Amerikaanse micro-netwerk waren typische multi-actor micro-netwerken. Ook de EGKS stelde bij het Brits-Nederlandse micro-netwerk eisen aan uitwisseling en samenwerking. Ten derde zouden nationale overheden bijdragen aan de plannen om in het Amerikaanse micro-netwerk en het Brits-Nederlandse micro-netwerk een demonstratie-fabriek te bouwen. Tenslotte, is het conventionele proces om ijzer te maken in veel geïndustrialiseerde landen onderhavig aan milieuwetgeving.

Een eerste conclusie is dat de subsidies door de overheid en de EGKS in vijf van de acht micro-netwerken additioneel waren. Dit heeft geresulteerd in een vergroting van het technologie-netwerk. Ook is het meeste van het geld besteed aan de ontwikkeling van smeltreductie-processen die waarschijnlijk uiteindelijk energie-efficiënt zijn. Toch hebben de financiële bijdragen van de overheden en de EGKS tot nu toe niet geleid tot een versnelde ontwikkeling van de technologie. Alleen het Corex proces is commercieel beschikbaar. Van de energie-efficiënte tweede-generatie processen maken het Japanse proces (ontwikkeld met overheidsgeld) en het Australische proces (ontwikkeld zonder overheidsgeld) de meeste kans om op industriële schaal toegepast te worden. Een tweede conclusie is dat de actoren die betrokken zijn in multi-actor samenwerkingsprojecten meestal ‘willen leren over de technologie’. De spin-off van samenwerkingsprojecten staat of valt met de betrokkenheid van actoren, die serieus inzetten op een verdere opschaling van de technologie. Een derde conclusie is dat het steunen of wegnemen van de risico’s voor een demonstratie-fabriek een aantrekkelijke strategie kan zijn voor de overheid. Dit is met name het geval als de bedrijven de technologie weldegelijk van strategische belang vinden, maar toch aarzelen. Het is echter een complexe taak. Bedrijven zijn zeer voorzichtig in het toelaten van derden (en zeker de overheid) als het gaat om risicovolle technologieën die de kern van het productieproces beïnvloeden. Een vierde conclusie is dat de prikkel die milieuwetgeving gaf niet groot genoeg was om de ontwikkeling van een complex en volledig nieuw proces als smeltreductie-technologie te beginnen. De verschuivingen in het technologie-netwerk van smeltreductie-technologie reflecteren de dynamiek van technologie-ontwikkeling in de staal industrie. De continue verbetering van de bestaande kapitaalgoederenvoorraad bij geïntegreerde staalbedrijven vertraagt de introductie van een innovatieve procestechnologie. Dit heeft het effect van de bijdragen van overheid en EGKS sterk beperkt.

## De dynamiek van ontwikkelingen in technologie-netwerken

In hoofdstuk 7 worden vervolgens eerst de vier case-studies vergeleken op zes aspecten. Deze zes aspecten hangen nauw samen met het kader dat we hebben gebruikt en met onze belangstelling voor overheidsinterventie.

<u>Actoren – De grootte en samenstelling van netwerken</u>

Producenten van papier en staal speelden een verschillende rol in de ontwikkeling van procestechnologieën. Grote geïntegreerde staalbedrijven investeerden zelf, terwijl papierbedrijven ‘wachtten’ op de toelevering door de internationaal opererende machinebouwers. De technologie-netwerken voor de papier-technologieën waren kleiner dan die voor de twee staal-technologieën. Meestal waren de actoren in bepaalde micro-netwerken op de hoogte van de ontwikkelingen in andere micro-netwerken. De monitoring, uitwisseling en interactie waren echter groter in de technologie-netwerken voor staal, dan tussen de mirco-netwerken voor de papier-technologieën.
In drie van de vier technologie-netwerken namen bedrijven het voortouw. In de vierde speelden papieronderzoeksinstituten, die gefinancierd worden door de nationale papierindustrie, een belangrijke rol. Alle bedrijven hadden aanzienlijke ervaring en een reputatie op het gebied van O&O. De directe rol van kennisinstituten en universiteiten was beperkt. In de meerderheid van alle micro-netwerken werkten actoren samen. Meestal kwamen de samenwerkingspartners uit verschillende landen. De belangrijkste redenen voor samenwerking waren het betrekken van belangrijke, aanvullende expertise of het delen van de kosten. Actoren hadden niet veel moeite om samenwerkingspartners te vinden. Wanneer er wel problemen waren, was dit in de fase dat de technologie op industriële schaal bewezen moest worden. Het was moeilijk om producenten te vinden die op grote schaal wilden investeren in een ‘onbewezen’ technologie.

<u>Artefacten – Duur en opschaling</u>

De ontwikkeling van energie-efficiënte procestechnologieën kost tijd. In alle vier de case-studies konden we een zogenoemde exploratie-fase en technologie-netwerk-fase onderscheiden. Het idee of principe van een innovatieve technologie was vaak al langer bekend. Vaak was er al eerder onderzoek uitgevoerd, voordat een robuust technologie-netwerk van de grond kwam. Op basis van de vier case-studies suggereren wij vier factoren, die een rol kunnen spelen in de overgang van de exploratie-fase naar de technologie-netwerk-fase.
Allereerst moet de technologie een economisch voordeel leveren. Deze factor is kritisch, maar niet afdoende. Een tweede, en erg belangrijke, factor is dat de innovatieve technologie nauw aansluit bij het reeds bestaande productiesysteem. De procestechnologie moet in te passen zijn en moet het totale systeem optimaliseren. Ontwikkelingen in O&O vormen een derde factor. Hierbij kan gedacht worden aan

nieuwe (fundamentele) kennis en inzichten. Maar wanneer de mogelijkheden van de conventionele technologie uitgeput raken, of wanneer concurrerende innovatieve technologieën niet echt van de grond komen, kan er ook ruimte ontstaan voor een technologie-netwerk. Tenslotte spelen contingente elementen een rol. Het was altijd een combinatie van factoren die er toe leidde dat actoren op een bepaald moment een innovatieve technologie (h)erkenden als de 'beste-volgende-stap' om het productieproces te verbeteren.

Op het moment dat een technologie-netwerk van de grond komt, duurt het nog steeds een flink aantal jaren voordat commercialisering van de technologie (misschien) plaats vindt. Afhankelijk van de technologie waren er twee of drie opschalingstappen nodig om de technologie te bewijzen. Elke stap duurde tenminste vijf jaar. Dus zelfs als een ontwikkelingstraject soepel verloopt, duurt de ontwikkeling van de technologie nog tien tot twintig jaar. Vaak is de technologie dan nog niet direct toe te passen voor alle producten van een bepaalde industrie.

<u>Agenda – De beloften die richting geven aan technologie-ontwikkeling</u>

In alle twee de industriële sectoren werden de innovatieve procestechnologieën ontwikkeld om de kosten per ton product te reduceren. Actoren verwezen naar de kenmerken van de markt waarin de producenten van papier en staal opereren om deze voorkeur te verklaren. In de zoektocht naar nieuwe procestechnologieën speelt het bestaande productieproces (en de omvangrijke kapitaalsinvestering van bedrijven in deze systemen) een sterk beperkende rol. Deze heeft grote invloed op de keuzen en beslissingen van actoren. De wereldwijd aanwezige kapitaalgoederenvoorraad zorgt voor vertraging en regelmaat in de ontwikkeling van procestechnologieën voor industriële sectoren; het bestaande systeem wordt in sterke mate steeds verder geoptimaliseerd.

In geen van de vier case-studies waren verbeteringen in energie-efficiëntie een doorslaggevend motief om de technologie te ontwikkelen. Alle technologieën grijpen in op de kern van het productieproces. Energiebesparing liftte mee op de ontwikkeling van belangrijke procestechnologieën.

<u>Dynamiek – Momentum</u>

We hebben het concept momentum geïntroduceerd om de dynamiek van de verschillende technologie-netwerken te karakteriseren. De case-studies lieten namelijk een verschil zien in de vaart waarmee verschillende netwerken een technologie ontwikkelden. Een technologie-netwerk heeft een groot momentum wanneer het ogenschijnlijk zo is dat de technologie zich autonoom ontwikkelt.

De technologie-netwerken van strip-casting en de schoenpers kenden een groot momentum. Het momentum van het technologie-netwerk van smeltreductie was kleiner, die van impulstechnologie nog kleiner. Tevens nam bij deze twee technologie-netwerken het momentum gedurende de ontwikkeling van de technologie af.

Momentum is een karakteristiek van het technologie-netwerk. Het is geen kenmerk van de technologie op zich. Het zegt ook niets over de fase van ontwikkeling van een technologie. Een verschil in momentum is niet alleen waar te nemen door buitenstaanders of observatoren, maar wordt ook door de betrokken actoren zelf vaak zo benoemd. Het momentum van een technologie-netwerk reflecteert het vertrouwen dat actoren (blijven) hebben in de perspectieven van de technologie. De innovatieve technologie blijft als het ware de ‘beste-volgende-stap’, ondanks verbeteringen in het conventionele productieproces en ondanks (structurele) trends en veranderingen in de industriële sector. Actoren moeten regelmatig bevestigd of herbevestigd worden in de perspectieven van de technologie.

Overheidsinterventie: Subsidiëring van O&O

De overheid heeft een aanzienlijke bijdrage geleverd aan de ontwikkeling van impulstechnologie en smeltreductie-technologie. De overheid droeg meer dan 25% bij van de totale investering in beide netwerken. Bij de ontwikkeling van de andere twee technologieën was de relatieve bijdrage nihil of zeer beperkt (niet in absolute termen). In alle vier de case-studies was het energie-efficiënte karakter van de procestechnologie een belangrijk argument voor de overheid om de ontwikkeling (eventueel) financieel te ondersteunen. Het verbeteren van de energie-efficiëntie was echter in geen van de gevallen voor de bedrijven zelf een doorslaggevend argument voor de ontwikkeling van de technologie. Actoren waren bedreven in het benoemen van het energie-efficiënte karakter van de technologieën om externe financiering te mobiliseren.
De subsidiëring door de overheid kan gerelateerd worden aan het momentum van de vier technologie-netwerken. Het valt dan op dat in de technologie-netwerken met een groot momentum, het effect van O&O subsidiëring beperkt was (strip-casting technologie en de schoenpers). In de gevallen waar het momentum van de technologie-netwerken lager was (smeltreductie en impulstechnologie), was het effect van de subsidies groter. Subsidies waren dan vaker additioneel en leidden tot een vergroting van technologie-netwerken. Tegelijkertijd illustreert de case-study naar impulstechnologie dat wanneer het momentum van een technologie te laag wordt, het effect van subsidies ook afneemt. In geval van impulstechnologie nam de twijfel of de technologie wel haalbaar is toe, waardoor de kans dat een van de actoren de technologie commercialiseert kleiner is geworden. Het vertrouwen is er niet langer.
Opvallend genoeg speelde de overheid in geen van de case-studies een rol in de exploratie-fase. Ook in de vroege fase van de technologie-netwerken waren het veelal de bedrijven zelf die het voortouw namen in het agenderen van de technologie. Subsidiëring door de overheid speelde in sommige gevallen een rol bij het verankeren van de technologie-netwerken.

Overheidsinterventie: Alternatieve strategieën

De overheid kan méér doen dan het subsidieren van O&O alleen om de ontwikkeling van technologieën te stimuleren. De empirische basis in deze studies voor dit soort alternatieve strategieën is niet erg groot. Toch is het interessant om een aantal observaties te vermelden.
Regelgeving zal niet snel een doorslaggevende factor zijn in de ontwikkeling van industriële procestechnologieën. Het speelde wel een rol. Het voorzag onderzoekers binnen een onderneming van een extra argument om de onderzoeksactiviteit voort te zetten. Het signaal van regelgeving werkt dus in de goede richting. Voor innovatieve technologieën die de kern van het proces raken is het signaal te klein (lees: het kostenvoordeel te gering) om een ontwikkelingstraject te rechtvaardigen. Bedrijven die een directe afspraak hadden met de nationale overheid voelden zich gecommitteerd aan die afspraak. Op deze manier kan een bepaald onderwerp of een bepaalde gewenste richting onder de aandacht worden gebracht bij ondernemingen. In verschillende micro-netwerken werkten een groot aantal actoren samen. Vaak werden deze multi-actor micro-netwerken financieel ondersteund door de overheid. Deze micro-netwerken hadden veelal niet het primaire doel om de innovatieve technologie te commercialiseren. Het is niet altijd even effectief om samenwerking te vereisen. Samenwerking was het meest effectief in een vroege fase van een ontwikkelingstraject. Dan willen actoren graag leren van elkaar's ideeën, inzichten en creativiteit. De spin-off van samenwerkingsprojecten staat of valt met de betrokkenheid en belangen van specifieke actoren.

## Kan het effect van overheidsinterventie vergroot worden?

De vier case-studies leiden tot een aantal beleidsrelevante conclusies. Ten eerste wordt de ontwikkeling van industriële procestechnologieën sterk beïnvloed door het bestaande productiesysteem voor industriële goederen. Soms wordt een aantal processtappen gecombineerd, maar toch optimaliseren de innovatieve procestechnologieën veelal het bestaande systeem. Ten tweede is de ontwikkeling van technologie voor industriële sectoren een langzaam proces. Ten derde is het moeilijk om de ontwikkeling van procestechnologieën effectief te stimuleren. Bedrijven bleken zelf vaak het voortouw te nemen in een ontwikkelingstraject. Toch was overheidsinterventie soms weldegelijk effectief en leidde het tot een vergroting van het technologie-netwerk. Ten vierde waren er – ondanks overeenkomsten in actoren en patronen in innovatie – aanzienlijke verschillen tussen technologie-netwerken. Zowel de omvang als het momentum van de technologie-netwerken verschilden. De betrokken actoren en hun geografische verspreiding verschilden. De belofte van 'innovatieve energie-efficiënte procestechnologieën voor de industrie' versluiert een grote heterogeniteit. Er is geen altijd geldige, standaard aanpak als het gaat om het stimuleren van technologie-ontwikkeling.

Op basis van deze conclusies zullen sommigen zich afvragen of de overheid de ontwikkeling van energie-efficiënte procestechnologieën moet stimuleren. Daarnaast komt de vraag boven hoe generiek of specifiek de overheid moet zijn. Het maatschappelijke belang van industriële energie-efficiëntie is echter groot. Dit is een reden om te blijven zoeken naar effectieve vormen van stimulering door de overheid. Het beperkte effect van overheidsingrijpen – zoals dat uit onze case-studies naar voren komt – is een tweede reden om te zoeken naar mogelijke routes om het effect van overheidsinterventie in technologie-ontwikkeling te vergroten.

De diversiteit in technologie-ontwikkeling tussen verschillende industriële sectoren en verschillende technologie-netwerken vraagt om meer maatwerk. De overheid moet kennis hebben van (internationale) technologie-netwerken voor een bepaalde sector. Ook moet de overheid kennis hebben van de actoren (hun capaciteiten, ervaring en reputatie), die de overheid direct kan benaderen of beïnvloeden. Op basis van deze kennis moet besloten worden of, en zo ja, welke interventiestrategie het beste aansluit bij het netwerk.
Het stimuleren van technologie-ontwikkeling kan niet altijd even effectief zijn. De resultaten van technologie-ontwikkeling zijn immers onzeker. Het is vaak moeilijk (en zeker vooraf) om te komen tot een kwantitatieve maat voor het te verwachte succes. Deze moeilijkheden bij het stimuleren van technologie-ontwikkeling maken juist dat andere (ook meer kwalitatieve) informatie gebruikt kan worden om het effect van interventie te vergroten. Onze analyse geeft hier aanknopingspunten voor. De inzet zal niet altijd het versnellen van technologie-ontwikkeling zijn. Soms is dit gewoon niet realistisch. Het is ook niet de bedoeling dat de overheid op de stoel van de industrie gaat zitten en de keuze maakt voor specifieke procestechnologieën. Maar kennis van het netwerk van actoren en de dynamiek in technologie-ontwikkeling levert extra inzicht dat meegewogen kan worden om te komen tot slimmere manieren van overheidsinterventie.

De volgende suggesties geven een eerste aanzet voor de verbetering van het effect van overheidsinterventie voor de ontwikkeling van industriële procestechnologieën:

- Een nationale overheid moet zich beraden op de actoren die zij kan beïnvloeden. Zij moet zich ook beraden op de rol die deze actoren kunnen spelen in internationale technologie-netwerken. Het is belangrijk om de kennisvelden te kennen waar actoren internationaal een reputatie hebben.
- Overheden kunnen het aantal actoren dat ze kunnen beïnvloeden vergroten door internationaal de krachten te bundelen. Er kan gedacht worden aan internationale O&O afspraken met een groep actoren (bedrijven) die een directe rol spelen in de O&O naar procestechnologieën. Op die manier kan het belang van energie-efficiëntie beter verankerd worden bij actoren die direct innovatieve procestechnologieën ontwikkelen. Er kan ook gedacht worden aan internationale O&O programma’s. Een derde optie is om op internationaal niveau de technologie-netwerken continue te monitoren. Alle overheden kunnen hun

voordeel doen met de kennis die zo gegenereerd wordt (niet alleen actor-kennis, maar ook technische kennis).

- Soms heeft een overheid niet direct toegang tot actoren die een rol spelen in de ontwikkeling van belangrijke procestechnologieën. Op basis daarvan kan de overheid de voorkeur geven aan indirecte interventiestrategieën. De overheid kan dan bijvoorbeeld komen tot ambitieuze meerjarenafspraken of stevige normen om het belang van energie-efficiëntie te articuleren. Ook kan men proberen om kennis over internationale technologische ontwikkelingen te ontsluiten (zowel ten behoeve van de industrie als voor de eigen kennis). In dit proces kunnen nationale kennisinstituten een rol spelen.
- Het is belangrijk om zicht te hebben op het momentum van technologie-netwerken voor specifieke procestechnologieën. Op basis daarvan kan ingeschat worden of overheidsinterventie überhaupt zin heeft. Het effect van interventie hangt af van het momentum van het technologie-netwerk. Het momentum moet niet te laag en niet te hoog zijn. Momentum kan in de loop van de tijd toe- of afnemen.
- Wat betreft keuze voor interventiestrategieën moet de overheid ook rekening houden met de fase waarin het technologie-netwerk zich bevindt. Wanneer een technologie-netwerk net van de grond lijkt te gaan komen kan de overheid een andere rol spelen dan wanneer het gaat om het op industriële schaal demonstreren van een innovatieve procestechnologie. In dat geval moet de overheid op basis van een grondige analyse van het internationale technologie-netwerk inschatten of het bouwen van een demonstratiefabriek de introductie van de technologie daadwerkelijk versnelt.
- Kennis van het netwerk van actoren en de dynamiek in technologie-ontwikkeling kan dus meegewogen worden om te komen tot slimmere manieren van overheidsinterventie. Wanneer dit gebeurt, is het van belang om dit soort kennis zo expliciet mogelijk te monitoren (om belangenverstrengeling en beïnvloeding te voorkomen). Het benutten van dit soort minder kwantitatieve kennis vereist een zorgvuldige afweging en onderbouwing.
- De overheid moet zich realiseren dat een lange-termijn commitment nodig is voor de ontwikkeling van energie-efficiënte technologieën. Technologie-ontwikkeling kost tijd. Wanneer de overheid zich langere tijd committeert aan een technologie, dan moet het internationale technologie-netwerk actief gemonitored worden. De ogen moeten niet gesloten moeten worden voor verbeteringen in de conventionele technologie en de opkomst van andere innovatieve procestechnologieën. Monitoren is noodzakelijk om te beslissen of, en wanneer, steun stop gezet kan worden.
- Het feit dat heel veel van de energie-efficiënte procestechnologieën meer doen dan energie besparen is geen reden om ontwikkeling van deze technologieën niet te stimuleren. De overheid moet de eigen agenda echter in de gaten houden. Het is belangrijk om grondige kennis te hebben van andere voordelen van procestechnologieën, maar ook van de mogelijke verbetering in energie-efficiëntie. Claims met betrekking tot energie-efficiëntie moeten kritisch bekeken

worden. Informatie over energie-efficiëntie alleen is niet genoeg om te komen tot zo effectief mogelijke interventiestrategieën.

- Wanneer de overheid de ontwikkeling van energie-efficiënte proces technologieën wil stimuleren moet zij enige flexibiliteit hebben om zo goed mogelijke bij het netwerk aan te sluiten. Zo is het bijvoorbeeld lang niet altijd nodig om de producenten te betrekken in onderzoeksprojecten.
- Interventiestrategieën die aangrijpen bij de vraagkant van technologie-ontwikkeling zullen voor veel energie-efficiënte procestechnologieën niet direct leiden tot een versnelling van de ontwikkeling. Zij geven echter wel een signaal af dat energie-efficiëntie belangrijk is.
- Het stimuleren van samenwerking in O&O kan een waardevolle strategie zijn, maar is geen garantie voor een versnelde technologie-ontwikkeling. De belangen en motivaties van de actoren geven informatie of het wel of niet zinvol is om samenwerking te vereisen.
- Als het gaat om het versnellen van technologie-ontwikkeling voor procestechnologieën voor de energie-intensieve industrie is er veel te winnen als de technologie-netwerken voor technologieën, die zich nog in een exploratie-fase bevinden, eerder versterkt kunnen worden. Een suggestie is om exploratieve ideeën te generen in een 'beschermde' omgeving door bijvoorbeeld onderzoekers, die een reputatie hebben als het gaat om de ontwikkeling en commercialisering van procestechnologie voor de industrie, financieel te ondersteunen om ideeën uit te werken.

De ontwikkeling van energie-efficiënte procestechnologieën is een aantrekkelijke optie om te komen tot een toekomstige reductie van broeikasgas. Het blijft een belangrijke taak voor de overheid om het belang van energie-efficiëntie, juist ook voor innovatieve procestechnologieën, te articuleren. Deze studie laat zien dat het labellen van een technologie als energie-efficiënt niet genoeg is om te komen tot effectieve vormen van overheidsinterventie. Het is van groot belang om interventie-strategieën te ontwikkelen die rekening houden met de opbouw van netwerken en met de dynamiek van technologie-ontwikkeling in industriële sectoren.

# Curriculum vitae

Ik ben op 26 januari 1973 geboren in Stompwijk. In 1991 slaagde ik voor het examen atheneum aan het Alfrink College te Zoetermeer. Geprikkeld om na te leren denken over ‘complexe maatschappelijke problemen’, begon ik in september 1991 met de nieuwe opleiding Natuurwetenschappen aan de Universiteit Utrecht. (Later is de naam van deze opleiding gewijzigd in Natuurwetenschappen en Innovatiemanagement.) Na een jaar extra onderwijs bij de vakgroep Communicatie en Innovatiestudies aan de Landbouwuniversiteit Wageningen studeerde ik in augustus 1996 af. Mijn afstudeeronderzoek heb ik uitgevoerd bij de sectie Natuurwetenschap & Samenleving, Universiteit Utrecht. Ik heb mij bezig gehouden met de mogelijkheden voor de Nederlandse overheid om de introductie van duurzame energie-technologieën te stimuleren.

Mijn interesse voor het proces van technologie-ontwikkeling heb ik verder kunnen verdiepen in mijn promotieonderzoek, dat ik eveneens heb uitgevoerd bij de sectie Natuurwetenschap & Samenleving aan de Universiteit Utrecht. Vanaf september 1996 ben ik als onderzoeker in opleiding aangesteld om onder begeleiding van prof.dr. Kornelis Blok te werken aan dit proefschrift. In een latere fase van het project is dr.ir. Harro van Lente van de disciplinegroep Innovatiewetenschappen betrokken geraakt. Tijdens mijn promotieonderzoek heb ik een kort onderzoek uitgevoerd naar de ontwikkelingen in Energie-onderzoek in Nederland (voor een internationaal vergelijkende studie van Pacific North-West National Laboratory, Washington D.C.).

Esther Luiten

# Het laatste woord

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You have all been subject to my ongoing questions regarding the development of particular industrial technologies. For me it was a valuable experience to approach such a variety of people from a large number of countries in order to get what I was looking for. I admire and appreciate the patience you had in helping me. The lists of questions appeared endlessly sometimes! I hope you appreciate what I did with the insights and stories you provided.

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