Green Markets and Cleaner Technologies (GMCT)

**What drives environmental innovations
in the Nordic pulp and paper industry?**

Paula Kivimaa, Petrus Kautto, Mikael Hildén & Juha Oksa

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Summary

Policy initiatives such as the Lisbon Strategy have highlighted the importance of environmental innovations as a key solution to many environmental problems and looked into different ways to promote them. Based on empirical cases in the Nordic pulp and paper industry, this report explores specific environmentally sounder technological innovations and their relation to societal and economic drivers, especially public policy. The report also discusses the activities of the Environmental Technologies Action Plan (ETAP) from the perspective of the pulp and paper sector. It is based on document analyses, interviews, workshop discussions and comments from the representatives of the Nordic forest cluster. The cases studied include the use of production by-products for energy, new products in the core business areas and new product value chains.

The cases of inventions and innovations examined in the report portray some key drivers and barriers for environmental innovations. The key drivers have included markets supporting more environmentally oriented innovations, often spurred by policy or customer pressure; access to a variety of relevant knowledge; environmentally oriented public and private funding; and new networks of actors. The main barriers that have slowed down the development of environmental innovations have included market inertia, policy support for traditional solutions, strong links between existing solutions and the whole production system, lack of risk capital, market failures with respect to environmental costs of energy and other raw materials, a narrow perspective and resistance to change of some actors, and lack or inefficient transfer of knowledge. The cases demonstrate the importance of different drivers and barriers, but for example the development of bioenergy-related technologies in the Nordic pulp and paper industry also shows that the ratio or the relationship between drivers and barriers can matter greatly.

Public policies, although not important in each individual case, can create a framework supporting environmental innovation and help to identify potential inefficiencies. Public policy has directly influenced environmental innovation in the pulp and paper industry through providing public R&D support, funding development projects and encouraging cooperation between different public and private actors, facilitating the crucial stage of demonstration with investment support and assisting in finding corporate funding, and creating or enforcing markets for environmental innovations through policies that encourage competition between different innovative options that have environmental benefits.

Although the formation of markets for innovation is increasingly dependent on international developments and environmental policies are greatly influenced by the EU, the basis for environmental innovations in the Nordic pulp and paper sector has been strongly linked with national innovation

systems (NIS). The Nordic educational policy which has created large pools of technical know-how has been instrumental in creating a foundation for the more direct ways of supporting innovations.

For the development of environmental policies and ETAP, the potential for the creation or enforcement of greener markets is important. The success of policy-created markets in supporting innovation is, however, crucially dependent on other simultaneous or subsequent market changes, for example, concerning prices of raw material or energy that push the development towards improved environmental performance. Environmental policies alone are seldom sufficient drivers for innovations.

The report has been prepared at the Finnish Environment Institute and it is part of a research project Green Markets and Cleaner Technologies - Leading Nordic Innovation and Technological Potential for Future (GMCT, 2006-2007) carried out in cooperation with the IIIIEE group at Lund University, the University of Aalborg and the Technical University of Denmark. The project was financed by the working group for Integrated Product Policy of the Nordic Council of Ministers.

1. Introduction

1.1 Background and contents of the report

Environmental innovation is a key solution to many environmental problems. Thus, recent policy discussions on national as well as EU level have highlighted the importance of environmental innovations and looked into different ways to promote them. On a more general level, the political emphasis on competitiveness, in particular through the EU's Lisbon Strategy, has underlined the need to find win-win solutions to environmental problems through innovations.

The European Commission has focused on the technological side of the issue especially through its Environmental Technologies Action Plan ETAP (CEC, 2004) (ec.europa.eu/environment/etap) and the Communication on Integrated Product Policy (CEC, 2003) (ec.europa.eu/environment/ipp). Similarly sectoral efforts, such as the EU level Forest-Based Sector Technology Platform (2006) (www.forestplatform.org) and the national strategic forest-based research agendas of the Nordic countries, address innovation with potential for generating environmental benefits.

Apart from forest sector activities, also recent strong developments in the bioenergy sector have implications on innovation in the forest sector. The EU Biofuels Technology Platform (www.biofuelstp.eu) and the Biofuels Advisory Council consisting of a multitude of stakeholders, including the forest industry, are important initiatives in this field. Recent changes in both the forest sector research agenda and in policy for environmental innovation form an interesting viewpoint for examining the driving forces and barriers for environmental innovation in the Nordic pulp and paper (P&P) industry.

This report documents results from the study Green Markets and Cleaner Technologies - Leading Nordic Innovation and Technological Potential for Future (GMCT, 2006-2007) based on empirical cases in the Nordic P&P industry. Overall, the report aims:

- 1) To identify policy interventions that have contributed significantly to the development and marketing of environmental technologies within the Nordic P&P industry.
- 2) To add to the understanding of key Nordic competencies in the innovation processes leading to cleaner technology and green market development that can further be enhanced by policy interventions.
- 3) To provide information on the P&P industry that can be used in developing the Nordic implementation of ETAP and other efforts to achieve sustainable production and consumption.

In addition, the report contributes to the overarching aims of the GMCT project "to add to the understanding of the dynamics, characteristics and influencing factors in Nordic innovations systems enabling/constraining the successful development, application and diffusion of environmental technologies" and to assess the feasibility of further supportive actions to enhance innovation competencies in different sectors

This study explores specific environmentally sounder technological innovations and their relation to societal and economic drivers based on document analyses, interviews, workshop discussions and comments from the representatives of the Nordic forest cluster. Particular focus is placed on the role of public policies in the promotion of environmental innovations. During the work Nordic experts on the P&P industry were contacted through e-mail to invite them to a workshop where the initial results were discussed and to offer them a possibility to comment on the draft report. The discussions of the workshop, which included six experts from the P&P sector, and comments on the first report draft from three other experts have been incorporated in this report. The authors, however, are solely responsible for the content of the report and the interpretation of the results.

The report is organized as follows. Chapter 1 shortly describes the P&P sector, followed by an overview of recent policy initiatives potentially influencing environmental innovation in the sector. Chapter 2 focuses on innovation by describing the innovation characteristics in the P&P industry and by reviewing previous studies on environmental innovation in the sector. Chapter 3 presents the methods used in the study and the new empirical findings in an analytical framework focused on the knowledge, resource and market elements in the innovation processes. Chapter 4 relates the findings of the literature review and the empirical cases to policy development, with particular reference to the Environmental Technologies Action Plan. The overall conclusions are presented in Chapter 5.

1.2 The pulp and paper industry in the Nordic countries

The pulp and paper industry is strongly tied to the history of the Nordic countries, and it has provided significant export revenues, especially for the economies of Finland and Sweden, throughout the 20th century. For these economies the forest-based sector is still a significant branch, pulp and paper contributing to 23 % and 11 %, respectively, of the value of total export in these countries (Table 1.1). In Norway the sector has divested its prominent status and plays now only a minor role, producing 2.5 % of the total value of export. In Denmark the role of the P&P industry is even smaller and for Iceland no production figures could be found. Through globalization of the industry, of its markets and the move of production facilities to places where the factors of production are inexpensive, the historically stable position of the Nordic P&P industry has during the last decade been replaced with uncertainty for the

future. This has influenced the economic behavior of the companies, and has contributed to, for example, increasing international investments.

Table 1.1. Pulp and paper statistics for the Nordic countries in 2003

Source: Finnish Statistical Yearbook of Forestry (Finnish Forest Research Institute, 2005)

	Finland	Sweden	Norway	Denmark
GDP per capita (USD in 2004) ¹	30 594	30 361	38 765	31 932
R&D expenditures, economy total (% of GDP) ²	3.51	3.74	1.75	2.63
Pulp production (1 000 tn)	11 948	11 737	2 389	0
Paper production (1 000 tn)	13 058	11 062	2 186	388
Pulp export (1 000 tn)	2 385	3 426	641	1
Paper export (1 000 tn)	11 734	9 080	1 871	230
Value of export in forest products (USD million)	12 032	10 923	1 655	373
Proport. of total export (%)	23.0	10.9	2.5	0.6
Forest available for wood supply (1 000 ha)	20 675	21 236	6 609	440
Share of forests in private ownership (%)	63	51	78	45
Collection of recycled paper (1 000 tn)	709	1 466	526	730
Use of recycled paper (1 000 tn)	688	1 926	456	400

Following an intensive period of consolidation during the latter half of the 20th century, international corporations dominate the market. The Swedish-Finnish Stora Enso, Swedish SCA and Finnish UPM-Kymmene are among the largest producers of pulp and paper in the world. The Norwegian Norske Skog and the Finnish Metsäliitto belong to the largest paper producers in Europe. In Denmark, two paper companies, Dalum and Hartmann, export globally but are relatively small actors. The P&P companies in the Nordic countries operate as part of a wider forest cluster that involves a variety of actors in research, production and supply processes. In addition to the pulp and paper producing companies, small and large consultancies (e.g. Pöyry and ÅF Consulting) and trade organizations are central actors. The production side involves equipment manufacturers, chemical producers, energy producers and forest owners. Innovation and market demand depend on public and private research organizations, and customers in existing markets (paper, packaging) and in new and anticipated markets (packaging, fuels, logistics, media). Due to the lowering price of paper and stagnating paper demand, the latter are becoming increasingly important.

The over 100-year history of the Nordic P&P industry is characterized by rapidly increasing production levels and improvements in the efficiency of production and utilization of natural resources. Initially the increasing production also resulted in increased environmental load. As a result the environmental impacts of the Nordic P&P industry have received much attention from the public over the second half of the 20th century. First, deteriorating water quality was addressed and, later, air quality.

The significant environmental impact areas of the sector have included water and air emissions, the use of natural resources, waste, and energy use. Despite rapid increases in production levels, the absolute water emissions

¹ www.oecd.org

² <http://epp.eurostat.ec.europa.eu>

have been significantly reduced due to a decoupling between production and water emissions in the 1970s. During the last two and a half decades, the relative use of raw wood has also been reduced by a quarter per tonne of paper produced. Both the waste resulting during production and the waste related to end products are now efficiently utilized. Energy consumption remains one of the largest challenges, as the P&P industry is a significant energy user in Finland and Sweden.

1.3 Recent policy and sectoral initiatives potentially influencing environmental innovation in the Nordic pulp and paper industry

The Environmental Technologies Action Plan (ETAP) of the European Union is a framework for developing ideas presented in the Lisbon Strategy, namely environmentally sounder technological progress that would also benefit the EU economy. It aims to "stimulate eco-innovation and the take-up of environmental technologies on a broad scale." (CEC, 2007: 3). Its overarching elements include the Communication issued by the European Council and the European Parliament in 2004 and the ETAP Policy Agenda which both list a variety of measures and activities to support the implementation of ETAP (CEC, 2004, 2007). ETAP includes the following actions in support of environmental technology (CEC, 2004):

1. Increasing and focusing research, demonstration and dissemination
2. Technology platforms
3. Environmental technology verification
4. Performance targets
5. Mobilization of financing (grants and loans)
6. Market instruments
7. Green public procurement
8. Awareness raising and training

The technology platforms, such as the Forest-Based Sector Technology Platform (FTP) and the Biofuels Technology Platform, are partnerships between public and private actors on a specific research topic. According to ETAP the idea of the platforms is for different stakeholders to jointly build a long-term vision for technology promotion and problem solving in particular areas. The FTP was initiated in 2003, and in 2006 it launched its Strategic Research Agenda that highlights areas with potential for environmental improvement, such as sustainable forest management, energy-efficiency and bioenergy, resource-efficiency, and greener chemicals improvement (Forest-Based Sector Technology Platform, 2006). The EU level action has been followed by the implementation of national forest sector research agendas in

eight European countries, including Finland and Sweden. One of the key areas is the development of leading markets.

The Biofuels TP was launched in 2006 and it relates to several EU policy initiatives, including the Biofuels Directive (2003/30/EC), the EU Biomass Action Plan (2005) and the EU Strategy for Biofuels (2006). The Biofuels Vision for 2030 recognizes the importance of industry residuals in the production of biofuels, lists integrated technologies in the pulp and paper sector in second-generation biofuels and aims at close links with the FTP (Biofuels Research Advisory Council, 2006). Both the FTP and the Biofuels TP tie into the idea of a European knowledge-based bioeconomy (CEC, 2006).

More concrete research projects have been carried out as part of the EU Framework Programmes and the ERA-Nets. FP6 has funded large projects, such as EFORWOOD, ECOTARGET and SUSTAINPACK in which several partners from many different countries cooperate. The ERA-Nets, which are networks of organizations funding research, have included, for example, ERA Wood Wisdom Net and ERA-Net Bioenergy.

Integrated product policy (IPP) is another extensive process that has been developed at the European level since the 1990s (see e.g. Rubik, 2006). IPP aims "to reduce the environmental impacts from products throughout their life-cycle" (CEC, 2003: 6), i.e., from raw materials extraction to disposal of products. So far, the implementation of IPP can be characterized as twofold: at policy level the Commission published a green paper on IPP in 2001 (CEC, 2001) and a communication in 2003 (CEC, 2003). Since then, it has commissioned several studies in order to identify and stimulate action on products with the greatest potential for environmental improvement³. On the more instrumental level, the products of the electrical and electronics industry have been a target of special attention of product-oriented environmental legislation (see also Box 2, page 36). So far, the P&P sector has received much less attention within IPP. The main exception is a directive on packaging and packaging waste that has been implemented based on extended producer responsibility in most European countries. Besides, innovations outside the core business areas are more likely to fall within the scope of product-oriented legislation.

Also other recent policy initiatives may influence the sector significantly. In the coming years, the regulation on chemicals and their safe use, REACH⁴, will affect both production processes and products. The developments in energy and climate policies, especially through emissions trading, are also of significance to future environmental innovation in the sector.

³ The products in the areas of food and drink, private transport and housing were identified as having the greatest impact (Tukker et al. 2006).

⁴ Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

2. Innovation dynamics and environmental innovation

2.1 Innovation characteristics in the Nordic pulp and paper industry

The innovation system surrounding the innovation activities of the Nordic pulp and paper industry is based on both the national innovation systems of the Nordic countries and the sectoral innovation system related to the industrial sector. Table 2.1. depicts relevant actors that form the innovation system of this sector. The national-level actors are generalized based on the operating conditions of the Finnish and Swedish pulp and paper sectors, and slight differences between the countries are likely. Public or other non-profit actors mainly form the national innovation system, whereas the other actors are, rather, related to sector-specific innovation systems that consist of both national and international-level actors. The distribution and existence of public and private actors is sector-specific as, for example, the role of education and research carried out in universities varies for innovation in different business sectors.

Table 2.1. The innovation system for Nordic pulp & paper sector innovations from an actor perspective

	National	International/EU
Public	<ul style="list-style-type: none"> • Science, technology, innovation policy councils • Ministries (innovation, trade, environment) • Governmental research institutes • Governmental innovation agencies (e.g. Vinnova, Tekes) • Governmental energy agencies (e.g. Swedish Energy Agency) and advisory bodies (e.g. Finnish Motiva and Swedish Swentec) • Universities (mostly public) • R&D funding foundations (e.g. Mistra, Sitra) • Venture capital (government owned) 	<ul style="list-style-type: none"> • The EU - DG Enterprise - DG Research - DG Environment - DG Energy and Transport - Joint Research Centre - European Science Foundation
Public-private partnerships	<ul style="list-style-type: none"> • Development finance companies (e.g. Finnfund) • Forest Cluster Ltd 	<ul style="list-style-type: none"> • Forest-based Sector Technology Platform • Biofuels Technology Platform • Biofuels Advisory Council
Private	<ul style="list-style-type: none"> • National industrial federations (SFIF, FFIF) • Sectoral research companies (STFI, KCL) • Small equipment developers/manufacturers (e.g. Chemrec, POM) • Energy producers (mostly national) • Customer companies (e.g. food producers, printing houses) • Venture capital (privately owned) • Private research foundations 	<ul style="list-style-type: none"> • CEPI • Pulp and paper producers • Large equipment developers/manufacturers • International consultancies (ÅF, Pöyry) • Chemical companies • New cooperators in automotive and electronics • Customer companies (e.g. food producers, printing houses) • Energy companies • Venture capital (privately owned)

According to the OECD classification system for manufacturing industries, the P&P sector is a low-technology industry (OECD, 2005). The R&D investments of pulp and paper producers tend to be clearly less than one percent of turnover, and much of the innovation has occurred in production processes, less in products. In process-based innovation P&P companies have cooperated with medium and high technology sectors, including equipment manufacturing, chemicals and information technology. Therefore the Forest Cluster, which the P&P sector is a part of, cannot be strictly characterized as low technology (Autio et al., 1997). Moreover, it has been argued that 'low-R&D industries are not necessarily low-innovation industries' as the Nordic pulp and paper sector shows (ibid.).

Much of the innovation activities in the Nordic P&P industry have taken place in Finland and Sweden. Finnish and Swedish paper companies have over the last two decades invested in R&D and cooperated with different actors through public research programs funding pulp and paper related R&D. For example, during the 1980s and 1990s the Nordic technology companies manufacturing equipment for the P&P industry were able to create competitive advantage through intensive cooperation. In Finland, cooperation between two technology manufacturers in the same public R&D programs, despite the existence of competition, increased the level of know-how and improved their competitive advantage in the world markets (Kivimaa and Mickwitz, 2004).

Compared to another important P&P producer, Canada, which for long has had a role of staple supplier to US markets, the Finnish and Swedish actors have relatively speaking been characterized by a greater emphasis on research and development (Lehtinen et al., 2004). The Norwegian P&P companies have largely been risk averse towards investments and have considered R&D merely as a cost. This has restricted the development of capabilities in the mills and excluded the exploitation of potential resources generated by the national innovation system, hampering Norske Skog in catching up technologically. (Moen and Lilja, 2001) The Danish paper industry, while always being small when compared with other paper producing nations, has been considerably reduced over the last 20 years, and is lacking public infrastructure that would support specific R&D in the paper sector (Andersen, 1999).

Overall, the R&D programs funded on both national and EU levels form a key part of the innovation system for the Nordic P&P industry. The Finnish Funding Agency for Technology and Innovation (Tekes) and the Swedish Governmental Agency for Innovation System (Vinnova) are significant actors in this field, although other funding agencies also exist. In Sweden, the Swedish Energy Agency, the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas) and the Foundation for Strategic Environmental Research (Mistra) are also relevant funders of research related to environmental innovations in the P&P industry. In Finland, other relevant public financiers include the Academy of Finland, the Ministry for Trade and Industry (MTI), the Ministry of Agriculture and Forestry, and the Finnish National Fund for Research and Development (SITRA). A number of R&D programs directly related to the P&P sector have been coordinated by Tekes and Vinnova, while the sector has also participated in more general technology

programs (see Table 2.2 for examples). The funding agencies, Tekes and Vinnova, have recently cooperated in carrying out the Wood Material Science Programme during 2003-2006. Research cooperation is further carried out by actors such as STFI and KCL, for example in EU-funded research and development projects.

Table 2.2. Examples of recent R&D programmes influencing the Finnish and Swedish pulp and paper sectors

R&D Programme	Duration	Funding Agencies	Country
Wood Wisdom - Finnish Forest Cluster Research Programme	1998-2001	Tekes, Academy of Finland, MAF, MTI	Finland
WDAT - Wood Design & Technology	2000-2006	Vinnova	Sweden
Wood Material Science Research & Engineering	2003-2006	Academy of Finland, Tekes, MAF, Formas, Vinnova	Finland & Sweden
Green Materials from Renewable Resources	2003-2007	Vinnova	Sweden
ClimBus - new business opportunities from climate change	2004-2008	Tekes	Finland
Serve - innovative service concepts	2006-2010	Tekes	Finland
Sectoral R&D Programme of the Forest Based Industry	2006-2012	Vinnova	Sweden
Biorefine - new biomass products	2007-2012	Tekes	Finland

2.2 Environmental innovation in the Nordic pulp and paper industry

Environmental improvements in the P&P industry can be linked to innovations in manufacturing processes, in products and in the development of emissions treatment. Innovation in these different categories is partly interlinked, because some new products require also renewed production processes and improved production processes may facilitate emission treatment. In the future the role of environmental system innovations relating to sustainable and efficient logistic and transport systems, product value chains and the biomass society may increase. Environmental innovation in processes and products can be further divided into sub-categories based on type of environmental improvement:

- Processes in pulp and paper plants
 - o Reductions in air or water emissions
 - o Improved resource-efficiency (chemicals, raw materials)
 - o Improved energy-efficiency
 - o Reduced water consumption
 - o Switching fossil fuels to bioenergy

- Products from wood fiber
 - o Improved durability
 - o Improved recyclability
 - o Reduced raw materials per unit
 - o Selection of environmentally less harmful raw materials
 - o Removal of hazardous substances

Innovations in the P&P industry can involve a single environmental improvement, such as a reduction in water emissions, or combine multiple improvements, such as improved energy efficiency and reduced water consumption. The magnitude of the environmental innovation can vary and an environmental innovation can also have negative environmental side effects (Hildén et al., 2002; Kivimaa and Mickwitz, 2004; Kivimaa, 2007a). For example, the Reference Document on Best Available Techniques in the Pulp and Paper Industry shows that there are many potential trade-offs in the use of different technologies (EC, 2001). This complicates the evaluation of which technologies can be considered to be environmentally friendly. While positive environmental effects partly define environmental technology, the point of comparison is ambiguous when assessing whether a certain technological solution is more environmentally beneficial than another. Even tools such as life cycle analysis examine environmental impacts separately, and the weighting of the different impacts is based on opinions, values and practices. (Kivimaa, 2007b)

Previous studies by the Finnish Environment Institute have dealt with process innovations that have reduced emissions, improved energy efficiency, and reduced water consumption (Hildén et al., 2002; Kivimaa and Mickwitz, 2004; Mickwitz et al., 2008) and product innovations that have made products lighter and more durable, improved recyclability and selected less harmful raw materials (Kautto et al., 2002; Kivimaa, 2007a). Other studies in the Nordic countries, based on a literature review, are rare and have mainly dealt with environmental regulation and improvement regarding water pollution (Laestadius, 1998; Sæther, 2000; Harrison, 2002).⁵ Reductions in water pollution and improvements in resource efficiency have been the major environmental improvements in the sector, the former often driven by environmental policy and the latter mostly by market factors (Foster et al., 2006).

Environmental innovation in the Nordic P&P industry has mostly focused on production processes rather than products. This is partly because environmental regulation and customer pressures have been targeting mainly at production, not products (Kivimaa, 2007a). On the product side environmental developments have largely focused on the use of recycled fibers, although paper and packaging companies have for decades also aimed to develop lighter and more durable products (Kautto et al., 2002). At the same time product innovation in general has received increasing attention. However,

⁵ The literature review covered English language sources, including Science Direct, Inderscience and Google Scholar.

so far, the main emphasis in the P&P sector has been on the environmental impacts of production (cf. e.g., electronics), while the focus of the work on environmental improvements has been on processes.

For the legislator the regulation of environmental impacts through products is demanding for economic and environmental reasons, especially in dynamic business areas. Products and product development are in the core of business and often complex product-related information needs to be obtained from several companies that are part of the product chain. In addition, even the same product can be manufactured, distributed and used in different ways, resulting in dissimilar environmental impacts. The information on the environmental impacts in turn is even more important for product policies than for policies regulating production, especially with end-of-pipe technologies, because the impacts are difficult to detect through use. (Kautto, forthcoming)

So far, environmental product innovations in the sector have mainly reduced the use of wood through improved resource efficiency and the use of recycled fibers. For example, through simultaneous development of paper and coating technologies it is now possible to produce approximately 80% more juice cartons from wood than in 1970 (Vesanto, 2007). In the future the large environmental potential of wood–fiber-based products lies in replacing products made of other raw materials than wood fiber, reducing the use of fossil fuel-based materials and also the environmental impacts of transport by offering lighter alternatives. Other environmental potentials lie in products communicating environmental information to users, decreasing product loss through safe and durable packaging and contributing to tracking systems developed in response to extended producer responsibility.

The role of environmental policies has clearly emerged in previous studies as the most discussed issue regarding environmental innovation in the Nordic P&P industry (Sæther, 2000; Hildén et al., 2002; Kivimaa and Mickwitz, 2004; Kivimaa, 2007a). It has not, however, been identified to affect all of the examined environmental innovations. Efficiency gains and customer demands have also been important drivers (Table 2.3).

Environmental policies have been effective in promoting innovation when they have been foreseeable in advance by companies, flexible in allowing testing of different technologies and gradually tightening (Hildén et al., 2002; Kivimaa and Mickwitz, 2004; Kivimaa, 2007). Sometimes inventions have been developed earlier but interest from companies has increased later when societal pressures regarding the environment have emerged (Sonnenfeld, 1998).

The possibility to react in advance of regulation has given leeway for the proactive companies to respond to political and market situations (Kivimaa and Mickwitz, 2004). For instance, the development of recycled corrugated board before any policy requirements aided a Danish paper company in influencing the European LCA standard (Andersen, 1999). Economic instruments and permit limits can both be flexible in allowing different types of technological solutions, but economic instruments must impose sufficiently high costs for inertia to make innovation attractive (Hildén et al., 2002; Mickwitz et al., 2008). Regulatory systems can create markets for innovation even when an

individual limit does not appear to provide incentives due to an expected tightening of the system in the future (Hildén et al., 2002). Permit processes as such can reshape networks of actors and expose operators to new information (Hildén et al., 2002). The success of environmental policy is also dependent on common understandings between government officials and companies and on the importance of the industrial sector being regulated at large (Sæther, 2000).

The importance of other factors than environmental policies was rarely mentioned in these studies. Kivimaa and Mickwitz (2004) have noted the importance of combined impacts of technology and environmental policies, globalization and cooperative networks of actors. Collaboration has also been highlighted by Andersen (1999) who has looked at interfirm learning with respect to innovation. Laestadius (1998) has examined R&D expenditure in the innovation process. Sonnenfeld (1998, 1999) has contributed part of the fast-track development in moving away from chlorine bleaching to a strong institutional role of environmentalists in the Nordic countries, while social movements in advanced and newly industrializing countries have helped gain funding for the technology development processes.

Table 2.3. Environmental innovation cases from literature

Empirical cases from literature	Demonstrated and potential environmental benefits	Economic, market & environmental policy drivers	Time	Sources
End-of-pipe technology				
Conox – process water effluent concentrate combustion system	Reduced water discharges (COD), somewhat improved energy efficiency	Anticipated regulation for closing the bleaching processes.	1990s–2000s	Kivimaa & Mickwitz, 2004.
Activated sludge treatment for waste water	Reduced water discharges	Environmental standards for organic loads (case-by-case permits)	1980s	Hildén et al., 2002
Filters for air emissions	Reduced air emissions	Air permits with emission limits and technology requirements	1980s	Hildén et al. 2002
Core process technology				
POM – air removing, compact pump system for paper machine	Improved energy efficiency; reduced water consumption, effluent discharge and waste compared to the conventional process.	Improved efficiency + in one case water permit affected installation decision	1990s–2000s	Kivimaa & Mickwitz, 2004.
From sulphite to sulphate process	Reduced water (BOD) discharges	Improved resource efficiency	1960s–1970s	Hildén et al. 2002
Non-chlorine bleaching of pulp	Reduced water discharges	Customer demand, strong environmental activism, regulation	1980s–1990s	Harrison, 2002; Hildén et al. 2002; Sonnenfeld, 1998
Closed water cycles	Reduced water use and discharges	Water emission limits, collaboration with chemicals manufacturers	1990s	Andersen, 1999
Process renewal	Reduced water discharges	Environmental regulation, customer pressure since the mid 1990s	1970s–1990s	Sæther, 2000
Other process technology				
Increased dry-solids content of black liquor (BL) recovery boilers	Reduced air emissions and improved energy efficiency	Improved efficiency, air emission limits for sulphur and nitrogen, cooperation between the government and industry	1980s–1990s	Kivimaa & Mickwitz, 2004
Oxygen delignification technology	Reduced water discharges (BOD, AOX)	Case-by-case water permits	1970s–1980s	Harrison, 2002
Products				
Recycled paper	Improved resource efficiency	Attempt to create a green niche market due to intense competition in paper markets	1990s	Andersen, 1999
Use of Chemo-Thermo Mechanical Pulp in three-layer board	Improved energy efficiency in transportation due to lower weight of packaging board	Pressures for improving cost efficiency, extended producer responsibility system especially in Germany	1990s	Kautto et al. 2002
Recycled corrugated board	Improved resource-efficiency	Improved cost efficiency	1950s	Andersen, 1999
Food packaging from wood-fibre	Replacement of tin cans, reduced environmental impacts from transport due to lower weight and improved use of space	Improvements in the logistics of packaged food, cost reductions, and the EU Directive on packaging and packaging waste.	1990s	Kivimaa, 2007

3. Cases of environmental innovation in the Nordic pulp and paper industry – methods, results and synthesis

3.1 Identification of cases

Based on a literature review of past innovation studies in the Nordic pulp and paper industry (see Chapter 2), the focus of the study was defined. Significant advances had already been made regarding traditional air and water emissions in the 1980s and 1990s, often encouraged by regulation (Ashford, 2005; Hildén et al., 2002; Gunningham et al., 2003). The focus of this study is on more recent developments and primarily on innovations/inventions improving resource efficiency and reducing the use of fossil fuels. Technological innovations however, may also simultaneously have other environmental benefits, such as reduced chemicals use. Improvements in resource efficiency and reductions in fossil fuel-based energy are important from the point of view of global energy and climate change issues. The increasing price of electricity creates pressure for more energy-efficient processes, while the intensifying competition for wood resources with bioenergy production further highlights resource efficiency in production processes and products. The efficiency improvements also benefit the environment.

The process of selecting the innovation cases for the study started with a review of trade journal articles from *Pulp and Paper International* and *Paper and Timber* published in 2000-2006. Because the information gained from the trade journal review was not sufficient, an e-mail questionnaire was sent to eleven P&P experts in Finland, Sweden, Norway and Denmark to solicit their views on what they consider successful Nordic P&P innovations in the 21st century. Based on five replies and information gathered from written sources, seven cases representing three commercialized innovations and four technologies in demonstration were selected for the study to examine the key drivers and barriers in innovation processes (Table 3.1).

Table 3.1. Short descriptions of the cases studied

Technology cases	Description	Potential environmental benefits	Economic / market drivers	Current status	Sources
Use of production by-products for energy					
Black liquor gasification for electricity (many developers in Finland and Sweden)	Producing electricity from a by-product of pulp making through a gasification technique	A CO ₂ neutral way to produce electricity, increases the yield of electricity compared to available technologies	1980s: low power to heat ratio of existing technologies 2000s: high oil price, EU emissions trading scheme	Failed to reach commercialization so far. Still ongoing R&D	Interviews: M. Hupa, Åbo Akademi, 14.11.2003; P. McKeough, VTT, 13.10.2006; P. Axegård, STFI, 31.10.2006 Literature: Kivimaa & Mickwitz, 2004.
Black liquor gasification for transport fuels (Chemrec, Sweden)	Producing demethyl ether (DME), a clean burning transport fuel, from a by-product of pulp making through a gasification technique	Reductions in CO ₂ emissions by replacing fossil fuel use in vehicles, has a higher efficiency than other options for producing transport biofuels	2000s: high oil price, EU created market for transport biofuels	At demonstration stage, expected start of commercial operation 2010-2011	Interviews: J. Rudberg, Chemrec AB, 30.10.2006; P. McKeough, VTT 13.10.2006; P. Axegård, STFI, 31.10.2006 Literature: Croon, 2005. Newspapers: Expressen 4.4.2005; Aftonbladet 24.8.2005; Nyteknik 30.8.2006. Other data: presentation by A. Røj, Volvo, 14.3.2007
Biomass gasification for transport fuels (VTT, Finland)	Producing transport biofuels by feeding additional biomass residues to a gasification process installed in integrated P&P mills	Reductions in CO ₂ emissions through replacing fossil fuel use in vehicles, has usually a higher efficiency than agriculture-based solutions for producing transport biofuels	2000s: high oil price, EU created market for transport biofuels, low global market prices for paper products (thus a need for new business options for the Finnish P&P industry)	At development stage, expected start of full-scale demonstration 2010	Interviews: P. McKeough, VTT, 13.10.2006 Newspapers: Tekniikka & Talous 20.9.2006, 21.9.2006; Turun Sanomat 12.10.2006; Helsingin Sanomat 1.11.2006, Helsingin Sanomat 17.3.2007 Literature: Finnish Forest Industries Federation, 2006.
LignoBoost (STFI, Sweden)	Extracting lignin, a chemical compound of wood, from the pulp making process e.g. for producing biofuels	Reducing CO ₂ emissions through replacing mineral oil	2000s: high oil price, increasing capacity of pulp production and extending the age of recovery boilers	At demonstration stage, expected start of commercial operation 2008	Interviews: P. Axegård, STFI, 31.10.2006 Newspapers: Nyteknik 7.6.2006
New production / products in the core business area					
Bleached Chemi-Thermo-Mechanical Pulp (BCTMP) mill (M-real, Finland)	A new type of mechanical pulp producing process that has higher efficiency and enables a higher level of whiteness in end products	Uses only half the amount of chemicals and less energy than the sulphate pulp process (when excluding the heat & power generated from sulphate pulping process). Reduced wastewater load due to an almost closed water cycle. Indirectly energy savings in transport due to reduced weight of products	1990s: improved efficiency and resource use of pulp production, economies of scale, new markets for products based on mechanically produced pulp	Started commercial operation in 2001, M-real has now three BCTMP plants in operation	Interviews: M. Leskelä, M-real, 2.11.2006 Newspapers: Pulp & Paper International, April 2002; Tekniikka & Talous 19.5.2005
Recycled packaging (Hartmann, Denmark)	Recyclable and biodegradable moulded fibre packaging made from recycled paper	Reduced material and energy use, reduced amount of waste	1990s: extended producer responsibility for packaging, packaging taxes for plastic packaging in some European countries, high oil price in 2000s	Products sold for decades, environmental arguments were first used in the 1990s, market is expected to grow worldwide	Interviews: T. S. Winther, Hartmann, 12.12.2006 Other data: www.hartman.dk
New product value chains					
RFID (many developers in Nordic countries)	Method for automatic identification, in which so called RFID tags or transponders are utilized for storing and remotely obtaining stored data. Tags can be attached to products, animals or persons	Reduced transportation due to improved logistics, reduced loss of products (e.g. timber), more efficient waste management and recycling, decreased amount of waste	2000s: increasing need for improving logistics due to longer supply chains and outsourcing, extended producer responsibility-based Directives for electronics and end-of-life vehicles	Market has expanded rapidly since the end of 1990s and is expected to grow significantly as tag prices decrease and technology improves	Interviews: T. Varpula, VTT, 26.10.2006; S. Strömberg, UPM Raflatac, 19.10.2006; M. Osswald, SCA, 25.10.2006; Li-Rong Z., KTH, 20.11.2006; several shorter discussions with a variety of people Newspapers: Tekniikka & Talous 28.9.2006 Other data: http://en.wikipedia.org/wiki/RFID
(UPM Raflatac, Finland)	RFID tags and inlays	See above	See above	Lots of potential and expectations, remarkable pilot projects with e.g. METRO Group	Interviews: S. Strömberg, UPM Raflatac, 19.10.2006 Communications at http://www.upmraflatac.com/europe/eng

3.2 Framework

The P&P cases are based on a combination of written and interview sources. The written information sources include previous research, trade journal and newspaper articles, web publications and sites, and annual reports. Interviews were conducted for each technology case. With the aid of literature on innovation systems and previous knowledge gained from conducting innovation studies at the Finnish Environment Institute, a case study framework was developed to be used in forming the interview questions and analyzing the findings (Appendix I). A common analytical frame examining the role of knowledge, markets and resources for environmental innovation was used in all the sectoral case studies of the GMCT project (see Figure 3.1). In this report the analysis of policy drivers has been incorporated into the market perspective in the form of policy-created markets.

Figure 3.1. Analytical frame used in the GMCT project (Source: IIIIEE, Lund University)

3.3 Markets – existing, new and policy-created

There have been three different types of market changes that have affected the emergence, development or commercialization of the studied environmental inventions: 1) Changes in the existing markets for P&P products have made producer companies aware of the need to improve the cost efficiency of production and economies of scale, to create new products for existing markets or to create products for new markets and product values chains; 2) EU-level environmental policies have created new or improved existing markets for bioenergy, CO₂ trading, RFID tags and inlays, and recyclable or recycled products; 3) Changes in other markets, such as in energy or electronics, have affected the search for efficiency improvements and for new product markets. The three types of markets changes have played a role in all or some of the studied innovation cases. Also, the review of literature on environmental innovation in the P&P sector indicates a similar conclusion (Table 3.2)

3.3.1 *Energy markets and resource-efficiency*

The development of the Bleached Chemi-Thermo-Mechanical Pulp (BCTMP) mill began from a need within M-real to increase the capacity of mechanical pulp production and improve its cost efficiency and achieve economies of scale. The cost per tonne of pulp would be reduced and new environmental improvements would also be achieved. Energy saving was a clear need from the beginning because energy prices were expected to increase in the future. Later customer needs and M-real's long-term goal to produce lighter-weight paper that maintains the functional qualities of a heavier paper were intertwined with the project because the BCTMP process enabled the production of pulp used for the lighter-weight paper. One of the driving forces of the development was that BCTMP pulp can be used in product groups that have previously used only chemically produced pulp, the new product being competitive because it weighs less because of the nature of the mechanically separated fiber. Paper with reduced weight offers cost benefits for the customers due to e.g. lower transportation costs.

Searches for mill-level efficiency improvements as well as for improvements in energy efficiency underlie also the so-called biorefinery cases (black liquor gasification, biomass gasification and LignoBoost). They are based on an idea that by producing also other products than the main P&P products, the cost efficiency of the mill as a whole could be improved. The price of and demand for energy products, however, need to be high enough to attract investments into the new energy technology. While the oil and electricity prices are currently high, the ideas behind the three cases of biorefinery-related technologies originated at a time when energy prices were low. The technology developers saw that the efficiency of the existing technologies could be improved and that a pulp mill could be a major supplier of energy.

Table 3.2. Influence of markets for environmental innovation in selected cases

Technological change	Time period	Changes in existing p&p markets	New markets created by environmental policy	Changes in other markets
Changes in the early 21st century				
Biorefinery innovations				
E.g. black liquor & biomass gasification, LignoBoost	2000 -	Pressures for improving cost efficiency and creating business in new product value chains	EU requirements for transport biofuels, national & EU support for RES, EU CO2 emissions trading	Increasing oil price, transforming electricity markets, new vehicle types
RFID innovations	2000 -	Pressures for creating business in new product value chains	EU policies for extended producer responsibility for electronics and end-of-life vehicles	Need for more efficient logistics, longer and more complicated supply chains, improved RFID technology
Changes during the 1990s				
Development of CTMP and BCTMP pulp to replace conventional mechanical pulp	1990s -	Pressures for improving cost efficiency and provide more competitive products	Extended producer responsibility system especially in Germany	Anticipated increased electricity price in the Nordic power market
Packaging from recycled materials	1990s -	Increasing price of wood –fiber in Denmark	Extended producer responsibility for packaging, packaging taxes	Increased (oil and) plastic packaging prices
POM – paper machine wet-end	1990s -	Improved efficiency, expansion of production to China and other new countries	(water emission limits in Spain)	
Conox – effluent concentrate combustion	1990s -	Expansion of production to China and other new countries	Expected national regulation for water emissions	"Discovery" of paper industries with higher organic contents in effluents than in modern wood-based paper industries
Changes during the 1980s				
Energy from black liquor through combustion or gasification	1980s -	Improved thermomechanical efficiency	SO2 and NOx emission limits in Finland	Low electricity price and regulated markets (hindrance)
Activated sludge	1980s -		Water emissions regulation in Finland	
Filters for air emissions	1980s -		National limits for air pollution	

A strong driving force for STFI to develop LignoBoost was that by removing lignin from black liquor, the pulp capacity of the mill can be increased with low investment costs. The system can also extend the age of existing recovery boilers up to 8-10 years, simultaneously saving 50-70% of the investment costs required to rebuild a recovery boiler. STFI has also parallel activities where it examines how lignin could be used to produce different products in the pulp mill biorefinery. The current high price of oil has increased investors' interest in LignoBoost, and two energy companies have been actively involved. Based on a market study, two applications of the technology have a potential of 100 process installations in the world. Pre-purchased licenses also show the growing interest of the market in this technology.

Gasification has long been viewed by its developers as a more efficient solution than recovery boilers to produce energy from black liquor. It needs less space, can increase the yield of electricity and also produce transport fuels. In the 1990s, however, technical uncertainties and a lack of benefits as perceived by the P&P industry hindered further developments. The estimated investment costs required to run a pulp mill with the gasification technology were significantly larger than for a mill using the conventional Tomlinson recovery cycle. The price of electricity was low in the Nordic Power Market and a fairly efficient existing alternative, the recovery boiler, offered a competitive alternative.

Despite the lack of interest from the P&P industry Chemrec continued the development of black liquor gasification for the production of electricity throughout the 1990s. Wider interest in the P&P industry did not arise until the early 2000s, when a directive for the promotion of biofuels for transport (2003/30/EC) was being prepared by the EU. The Directive requires that the Member States achieve a minimum proportion of 2 % of biofuels in the energy content of transport fuels by 31 December 2005 and 5.75 % by 31 December 2010. Thus the directive has created a market for new technology, while the increased price of oil has enhanced the competitiveness of biofuels at the same time. Initially two engineers at Chemrec were looking at other applications for black liquor gasification. Following the new demand for transport biofuels Ingvar Landälv, technical director of Chemrec, came up with the invention to combine syngas and pulp production to produce dimethyl ether (DME) for a transport fuel. Another economic driver have been the energy tax reliefs for renewable fuels in Sweden that make the net payback time quicker. DME costs as much as diesel to produce but environmental charges and taxes do not have to be included in its selling price.

Following the Directive, Chemrec has established cooperation with Volvo, which has developed a truck engine using DME as fuel. Volvo is interested in the cooperation because it anticipates a future with stringent requirements for emissions from heavy-duty diesel engines. Climate change, projected availability of energy sources and energy security act as key drivers for ~~future market~~ developments in transport fuels. Volvo is planning to start the commercial production of DME engines in 2011 and wants to have a large-scale demonstration project from Chemrec for having the fuel commercially available. The demand from Volvo has been very important for Chemrec, and

since 2007 Volvo Technology Transfer has also been a co-owner of Chemrec. Worldwide, Chemrec sees a potential market of replacing around 400 recovery boilers with black liquor gasification when the recovery boilers reach their end of life in Sweden, Finland, the US and Canada. The technology is applicable to non-integrated pulp mills as well as integrated P&P mills.

Box 1. Summary of the drivers and barriers for bioenergy related technologies in the P&P sector

The Nordic P&P industry has been and still is an important actor in Finnish and Swedish energy policy for several reasons. First, it has been a significant user of electricity (30% of all consumption in Finland) and, second it has shaped the power generation structure by becoming a significant producer of bioenergy. More than forty percent of the consumption of renewable energy in Finland (including large-scale hydro) is based on black liquor and other concentrated liquors that are mainly by-products of the pulp and paper production processes (Statistics Finland, 2004). This has involved innovations from the 1970s to the 1990s in the recovery boiler technology used to combust black liquor, the by-product of pulp manufacture, to produce heat and electricity. More recent R&D developments in the sector, however, are increasingly focused on both other technologies (e.g. black liquor gasification, Ligno-Boost) converting black liquor into energy and on other end products resulting from the conversion (transport biofuels).

The context for bioenergy-related innovations has changed over time and, interestingly, one can identify a variety of drivers and barriers affecting the developments in bioenergy technologies applied in the P&P industry during 1980s - present. The developments show that significant progress has required strong drivers that have helped to overcome the barriers for innovation.

In the 1980s, much public and private R&D was carried out on both combusting and gasifying black liquor for electricity. A multitude of drivers supported the commercialization of new combustion technology, while the development of gasification technology was hindered by technological uncertainty and the risks it entailed for potential investors. Cost factors, i.e. low efficiencies in utilizing black liquor, and the anticipation of new air pollution control policies following a public concern for industrial air emissions directly influenced the development and commercialization of a new technology increasing the dry solids content of black liquor. Other contributing factors to the success of the innovation process included intensive R&D cooperation and public R&D funding on black liquor, the oil crises of the 1970s followed by an emphasis on wood fuels in energy policy, and discussions on nuclear energy (Kivimaa and Mickwitz, 2004).

In the 1990s, the operating framework changed: the number of drivers was somewhat reduced as R&D activities decreased, and simultaneously the number of barriers increased. The diffusion of the new combustion technologies from the 1980s continued following permit conditions based on new air emission standards for sulphur dioxide. The opening up of Nordic electricity markets and scientific and political debate on climate change also supported the diffusion to some extent. The opening of markets created an incentive for some pulp and paper companies to produce electricity exceeding their own needs and to thus employ more efficient boiler technology. (Kivimaa and Mickwitz, 2004) Climate change further emphasized the importance of bioenergy in national energy policies. At the same time, continued technological uncertainty regarding gasification technology, despite continued R&D efforts by Chemrec, and a low oil price made pulp and paper companies uninterested to invest or participate in the demonstration of new, uncommercialized technologies. Therefore, little innovation was achieved on a Nordic scale during this decade.

At the beginning of the 21st century, new market and policy developments created a window of opportunity for black liquor and biomass gasification technologies (as well as other technologies such as LignoBoost) developed in previous decades. An EU directive for transport biofuels launched in 2003 created a new market for these technologies as the demand for biofuels increased due to legislative requirements. This combined with an increased oil price and the pulp and paper producers' need to seek new business opportunities (due to tightening competition in world paper markets) has made the producers more interested to invest and test the new biofuel-producing technologies. Increased concern for climate change, EU emissions trading supporting renewable energy and the expected opening up of EU energy markets have also created potential for gasification technologies applied to electricity production. Yet the end result of these developments is still unclear, because there are also several potential barriers. The drivers are of general nature offering also opportunities for bioenergy produced by other means. Thus other technological options for producing biofuels act as a barrier together with possible price support for competing renewable energy sources, e.g. through agricultural policies. Availability of wood resources will also influence the success of these ventures. The next few years will show what happens.

The EU Biofuels Directive together with security of supply concerns and increasing price of oil also drive technological development for producing transport fuels from biomass gasification. Biomass gasification has long been researched in Finland, and thus suitable technology is near commercialization to respond to the current EU requirements. The low price for oil has, however, kept many research results unutilized until recently. The interest of the forest industry has been low until lately and Finland has only recently brought the requirements of the EU directive into force. UPM has taken the first move among the forest companies and stated that it will start the production of DME through gasification in connection with its pulp mills in Finland and in other European countries. Stora Enso has also announced a co-operative venture with Neste Oil to start the production of biodiesel.

The globally decreasing price for paper products, stagnating paper demand and an increased price of fossil fuels have only recently increased the interest of P&P producers towards biorefineries. Finland has not focused on black liquor gasification like Sweden, partly because the Finnish pulp mills use much of the black liquor for producing electricity and heat from fairly new recovery boilers. Thus, they perceive biomass gasification as a more viable option in the near future. It is slightly more expensive than black liquor gasification, but the technology can also be applied outside the P&P mills – i.e. with export potential for larger markets. On the other hand, biomass gasification in connection with pulp production always requires an integrated P&P mill. What has served as a driver for Neste Oil is that although biomass gasification has higher manufacturing costs there are no extra infrastructure costs on top of the existing distribution system.

3.3.2 Product tracking and packaging

For several reasons, but especially due to increasing outsourcing of manufacturing, the need to improve supply chain management in many industrial sectors has been stressed in recent years. One way to support the supply chain management is RFID technology. In recent years, RFID technology has become less expensive and more usable as electronics and integrated circuits have developed rapidly. In connection to its labelstock business area, UPM Raflatac and its predecessors have for years developed RFID tags and inlays in order to create new business in this rapidly changing environment. Finally, the EU directives on extended producer responsibility (EPR) for electronics⁶ and end-of-life vehicles⁷, have created significant pressures to enhance waste management and recycling in these industries and thus created new markets for RFID Technology-based solutions, too.

⁶ Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE).

⁷ Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of-life vehicles.

EPR-based systems for packaging and packaging waste have also created new markets for recyclable and biodegradable molded fiber packaging, which, for example, the Danish Hartmann company has produced for decades. This development has taken place despite less ambitious goals set in the directive for the recycling of plastic than for fiber packaging. In addition, a tax on packaging has favored fiber packaging over plastic in some EU countries. Finally, higher oil prices have also increased the price of plastic and thus supported the growth of the molded fiber packaging market.

3.3.3 Summary of market drivers

The case studies show that the classical drivers of innovation, i.e. the needs to improve the cost efficiency of production and economies of scale, to create new products for existing markets, or to create products for new markets and product value chains have been significant also regarding environmental innovations in the P&P sector. Parts of the new or improved existing markets have clearly emerged as a consequence of policies as shown by bioenergy, CO₂ trading, RFID tags and inlays, and recyclable or recycled products. Furthermore, changes in other markets, such as in energy or electronics, have had spillover effects that have contributed to the search for efficiency improvements and new product markets also in the P&P sector.

The findings of the cases suggest that interacting changes in markets (paper & packaging, policy-created, other) are often needed to spur the commercialization of environmental innovations. Markets created or enforced by environmental policies may be crucial for those innovations that provide significant benefits for environmental protection but that at least initially appear to be technologically uncertain or significantly different from the current production and consumption systems (e.g. biofuels, packaging in some sectors). Another observation is that a single strong market driver can affect innovation in different spheres. The increasing oil price has affected different technological developments by directing attention to 1) the weight of products that affect transport fuel needs; 2) the creation of alternative transport fuels reducing dependence on oil; and 3) new packaging materials offering alternatives to fossil-based packaging.

3.4 Knowledge – pools, access and different types of knowledge

Both codified and tacit knowledge is used in the innovation process, within companies and through inter-organizational cooperation. Based on the empirical cases, the nature of knowledge used and its importance has varied in different parts of the innovation process, and in most of the cases a

combination of knowledge sources has been used. The cases also show that the original idea or the invention behind a new technology can originate from different sources of knowledge. The following looks at three different types of knowledge sources as initiators of environmental innovation processes and provides concrete examples of cases where these have occurred:

- 1) knowledge generated through publicly funded research (including long-term investments in R&D, initiatives for cooperation and incorporation of environmental objectives);
- 2) knowledge generated by market and competitiveness concerns (involves pooling company internal knowledge e.g. due to process inefficiencies or market changes);
- 3) knowledge spurred by combining information from different business sectors.

Knowledge generated through publicly funded research can function as a start for the development of new process technologies. This corresponds to the traditional view of a technology push-based innovation process. Biomass gasification in Finland is a case where the knowledge generated and diffused through public R&D programmes has played an important role. The Technical Research Centre of Finland (VTT) and the Helsinki University of Technology (HUT) have studied biomass gasification since the 1970s, and the Finnish Funding Agency for Technology and Innovation (Tekes) has funded gasification projects in its technology programs since the 1980s. Later, a consortium of researchers and companies has formed to jointly develop biomass gasification in integrated P&P mills. Researchers from VTT and HUT have worked together with two technology-developing companies. Potential users of technology have also been involved, including three large energy companies and the forest industry in Finland. In addition to knowledge diffused through public R&D funding, public mechanisms have given signals of the need of bioenergy technologies through various renewable energy policies at national and EU levels.

In the market pull model an idea behind an innovation can start from pooling company internal knowledge to solve problems or respond to new market needs. The process of developing BCTMP started from awareness within M-real, a Finnish P&P manufacturer, that the company's existing pulp mills were getting older and producing too little pulp too inefficiently. The research director of M-real pooled knowledge from different parts of the company to generate ideas for renewing pulp production and, through the process, the internal efficiency needs were combined with M-real's market strategy to produce lighter-weight products without reducing their functionality. Later, technical universities, the technology company Metso and the chemicals manufacturer Kemira also took part in the project. M-real obtained funding from Tekes partly because the company was cooperating with some smaller companies as well.

Technology push and market pull often operate simultaneously. In the development of the LignoBoost process at STFI, a private research and consulting company, knowledge generated through research and potential new

markets influenced the invention phase. In 1996, research at STFI was based on a vision that a pulp mill could be a major supplier of energy to the society. At the time many people in the P&P industry viewed this as unrealistic, partly because the price of oil was low. Research at STFI was based on the idea that lignin could be removed from black liquor to produce fuel that could, for example, replace mineral oil. LignoBoost was developed further in cooperation with companies, universities and the Foundation for Strategic Environmental Research (MISTRA) and with support from the Swedish Energy Agency. The increasing oil prices have made the P&P industry perceive energy products as a potential business, but the Swedish green certificates scheme somewhat discourages investments in LignoBoost due to the profitability of producing electricity from excess steam in pulp mills through existing processes.

The technology push may not only arise through formal R&D. A new idea can also emerge through combining experiences from companies operating in different industrial sectors. The pooling of tacit knowledge from different areas may lead to innovations. Chemrec's process of developing black liquor gasification began in the late 1980s when an engineer, with a background in the P&P industry, inferred that gasification technology used in the oil and gas company where he was working could be applied to black liquor due to its resemblance to heavy crude oil. He developed the idea further with a friend working in P&P equipment manufacturing. The ownership of Chemrec, the company established to develop the technology, changed several times in the course of 20 years between companies having either expertise in P&P equipment or oil and gas gasification, while many technical problems remained unsolved – in one case due to an inefficient knowledge transfer between Kvaerner's regional offices. Finally, the problem of finding materials that could withstand corrosive chemicals was solved with the help of a US national laboratory specialized in materials for space shuttles. Chemrec also sought help from a consulting company, ÅF, and worked together with Swedish universities and STFI. The Swedish Energy Agency has funded the development since 1997 and helped Chemrec to negotiate corporate finance. At later development stages, when the technology has been closer to demonstration, potential companies to invest in the technology from the forest industry and the potential end users of the products in the energy sector have become involved through funding and expertise sharing. Part of the interest has been fuelled by signals from EU policy for supporting transport biofuels. Inter-organizational cooperation and public knowledge pools have been important for black liquor gasification.

In addition to overlapping technology push and market pull, the development of RFID technology in P&P industry arises through the combining of technologies from different industrial sectors. RFID technology itself has its origin already in the 1940s, but only the rapid development of electronics and integrated circuits in the past decades has enabled the emergence of new types of RFID appliances. Besides the more common trend and use of RFID to rationalize logistics in the sector, UPM Raflatac and its predecessors have developed RFID tags and inlays for nearly ten years. The development work has been carried out in cooperation with a variety of public research institutions and private partners, e.g., large retailer companies. Gradual advances in

technology have enabled the production of label-like and printed tags, which have numerous uses in different applications.

In sum, the knowledge initiating an idea or an invention is based on many different sources and types of knowledge: basic research and research networks, pooling company internal knowledge, entrepreneurial thinking, combining experiences with different business sectors, or combinations of technology push and market pull. Thus, access to and interest to seek a variety of knowledge pools is important. The challenge is how to integrate environmental considerations as standard parts of these processes (cf. Kärnä 1999). The public sector can clearly influence the diffusion of environmental objectives into the knowledge creation process through criteria for research funding, development of educational curricula and, as noted in Section 3.3, by creating or enhancing markets that can attract information from different business sectors.

3.5 Financial and human resources

3.5.1 Financing innovations

Financial resources for developing innovations have been found within the companies doing the main development work, from other sources of private funding and through public support. Public support has been used in all the studied cases, although in the case of molded fiber packaging, public funding has only been used in recent years in order to develop the replacement of plastics by bio-based materials. Public funding for innovation in the Nordic pulp and paper industry has usually been obtained from national funding organizations in Finland or Sweden. It has been supplemented with private and corporate funding. The form of private funding has differed between cases, including ownership in the technology-developing company, loans, and pre-purchase of licenses.

In the later development stages, consortiums of companies and research organizations have been common, where funding is usually obtained from the participating companies and a public funding agency. Getting the pulp and paper companies to participate and invest in a development project has in some cases been difficult. The development of molded fiber packaging by Hartmann and RFID tags and inlays by UPM Raflatac have mainly been done by corporate funding and within consortiums of private actors. In the more general development of RFID technology development at VTT and KHT, the role of public funding has been crucial.

Over the years, the Nordic P&P companies have had little interest to invest in the development of black liquor gasification, partly because the investment costs have been high and the technology yet uncertain. The potential benefits of black liquor gasification have been perceived too low to attract

pulp mill owners to invest in demonstration plants. Thus, in the early 1990s many efforts were stopped due to lack of funds. For ten years, since the late 1980s, the development of black liquor gasification in Chemrec was mainly financed by its large owner companies, including Kvaerner Pulping and Babcock Borsig Power GmbH. During the late 1990s, when the large owner companies experienced financial problems and divested their ownership in Chemrec, public funding from the Swedish Energy Agency was crucial to keep the company afloat, to guarantee payment of components and to persuade companies to invest. During the 21st century, when the technology has been closer to commercialization, other companies have been convinced to fund the development, while the P&P industry has been the hardest to persuade. Part of the funding from the P&P companies has been in the form of man hours, i.e. competence. Despite negotiations, no Finnish pulp and paper companies had participated in these efforts by the end of 2006.

The development of LignoBoost has been partly funded by pre-selling licenses of the new technology before it has been ready for commercial use, because the company developing the technology has not wanted to sell its ownership. Pre-purchased licenses are less costly for the companies that buy them but entail uncertainties of unfinished technology. In the development of BCTMP obtaining funding has not been an issue, because as a large company M-real has been able to self-invest in the project. Still, public funding from Tekes has also played a role in developing the technology.

On the monetary resource side, largely the same logic and preconditions apply for environmental innovations as for innovations in general. The public sector has provided additional funding sources for innovative ventures. For example, in Sweden the Foundation for Strategic Environmental Research (Mistra) has been a potential source of funding for environmental technology development. In Finland, R&D programs such as CACTUS have included environmental objectives and directed the development of technologies into that direction (Kivimaa and Mickwitz, 2006). Environmental venture capital is also important, especially for commencing SMEs that often cannot find corporate finance or public funding. Public actions can also influence the perceived ratio between risk and expected benefit. Consistent long-term public policies can reduce the non-technical risks and increase the expected benefit of environmental innovations creating or contributing to developing markets.

3.5.2 Human resources

Underlying the Nordic innovation cases is educational competence that can be perceived as a part of both national and sectoral innovation systems. The high level of education in the Nordic countries and a specific focus on technological higher education in fields that are relevant for the P&P industry have supported innovation in the sector.

Networks of actors have been crucial for all the innovation cases. Competence has usually been pooled from different organizations, as the competence needs vary in different parts of the innovation process. Public intervention has in some of

the innovation cases created conditions for new networks of actors to emerge and function. Besides the basic maintenance of universities and research institutes, where basic research is carried out supporting the more applied research done by companies, public research programs have encouraged cooperation between different public and private actors. For instance, in the case of BCTMP pulping, Tekes allocated funding to M-real because of its cooperation with smaller and medium-sized companies. The nature of public funding made Chemrec seek active cooperation with universities in developing black liquor gasification for transport and it also received support from the Swedish Energy Agency for finding suitable corporate partners to fund the development project. Environmental policies have also motivated new types of networks. The EU Directive on transport biofuels has intensified and created new cooperation between the P&P sector and the energy and transport sectors. In the development of RFID, public funding created cooperation in the early stages but the later networks between commercial actors have mainly been induced by market developments.

While the participation of different organizations is important, entrepreneurial individuals are also crucial for the emergence and development of innovations. This is highlighted in an example of the development of black liquor gasification at Chemrec. The fact that Chemrec has reached the near commercialization status of black liquor gasification is largely the result of the work of many devoted individuals. In the starting phase, an engineer and his friend were instrumental for the original technical solution and its patent. Later, in 1993, when Kvaerner was the main owner of Chemrec, the project came to a standstill when a major sponsor of the project died. Since 1997, when Kvaerner made an executive agreement with Nykomb whereby experts in oil and coal gasification started running the project, the chairman of Nykomb has been a dedicated supporter of Chemrec and perceived black liquor gasification as the technology of the future. The people at Chemrec have worked very hard for the project, sometimes even without pay, and a person at the Swedish Energy Agency has helped them to negotiate funding.

The public sector cannot on its own “produce” entrepreneurial individuals. It can support them through an educational system that provides a basis for creative and independent thinking, and by contributing to risk funding, in particular in the early phases of company development.

4. Key factors affecting the innovation process

4.1 Drivers of innovation

The cases of inventions and innovations examined in this study enable the identification of some key drivers and barriers for environmental innovations. Chapters 2 and 3 showed that the key drivers include markets that support more environmentally oriented innovations, often spurred by policy or customer pressure; access to a variety of relevant knowledge; environmentally oriented public and private funding; and new networks of actors. The development of bioenergy-related technologies in the Nordic pulp and paper industry shows, however, that in addition to the type of drivers also the ratio or the relationship between drivers and barriers matters (see Box 1). Public policies, although not important in each individual case, can create a framework that supports environmental innovation and help to identify potential inefficiencies.

Public policy has directly influenced environmental innovation in the P&P industry in three different ways: (1) in the form of public R&D support, funding development projects and encouraging cooperation between different public and private actors; (2) easing the crucial stage of demonstration by investment support and assisting in finding corporate funding; and (3) creating or enforcing markets for environmental innovations through policies that encourage competition between different innovative options that include environmental benefits. In addition, the Nordic educational policy that has created large pools of technical know-how has been instrumental for the more direct ways of supporting innovations.

Based on the findings, environmental policies can have a crucial role in shaping or creating markets for innovations that tackle the challenges related to climate change and other environmental problems. EU level policies have a greater capacity than national policies to create demand for environmental technologies and products, but there are also examples of how relatively local regulations can provide key incentives for innovation (Hyvättinen and Hildén 2005). It is therefore important that environmental policies have flexibility to accept different kinds of innovations meeting the demand rather than supporting pre-selected options (cf. Kivimaa, 2008). This includes both flexible regulation and economic instruments that impose high enough costs for inaction.

In some cases, inventions offering potential solutions to environmental problems may be dependent on markets created with the help of public policies

in order to become environmental innovations. The bioenergy development is a case in point. New markets are crucial for motivating the companies to invest in new technologies and products. One of the studied cases showed that continued support for existing environmental technologies, such as renewable energy, can also slow down innovation by making the existing technologies too profitable to be improved, even when a better solution from an environmental point of view already exists.

Environmental policies have affected all technological changes described in this report either directly by creating new markets for innovations or indirectly through environmental requirements in the waste management of other sectors. A difference in the environmental policy-created markets can be observed in that, while previously the markets were often created by national-level environmental policies, the new environmental policy-created markets are based on EU-level policies. Therefore, the way in which environmental policies are designed (to be supportive or non-supportive of a wider range of innovations) has more extensive implications on technological development in Europe.

Environmental policies in the Nordic countries and the EU have also indirect impacts on global technological development because many P&P technologies developed in the Nordic countries diffuse to worldwide markets, such as China and South-East Asia (e.g. Sonnenfeld, 1998; Kivimaa and Mickwitz, 2004). The EU legislation may also have a global impact: in the electronics sector subcontractors outside Europe have changed their ways of operating in order to conform to EU legislation and EU has acted as a model for legislation in e.g. China (Kautto and Kärnä, 2006). However, due to differences between the pulp and paper and electronics industries, the focus of environmental policies for these sectors will probably be different also in the future (see Box 2).

Box 2: Product oriented policies for pulp and paper industries: What can we learn from the electronics?

Products of the electrical and electronics industry have in recent years been a target of special attention in EU product-oriented environmental legislation. Three new directives (RoHS, WEEE and EuP) have been approved in 2003-2005 aiming to reduce the negative environmental impacts of electrical and electronic equipment and energy-using products. The requirements of the directives apply to the design, manufacture and waste management of these products.

Based on the experiences gained on these directives so far, the following lessons can, for example, be drawn:

- The use of companies as "regulatory surrogates", i.e. making them responsible for their contract manufacturers and subcontractors (cf. Gunningham & Sinclair 2002; Vedung 1997, 153) creates possibilities for environmental product policies in a situation where production is increasingly shifting outside the EU region. In the electronics sector, however, the supply chain management does not go without problems: the availability of information varies and the task of compiling information and assessing its reliability requires a great amount of resources (Kautto & Kämä 2006). The pulp and paper companies have already been made liable for sustainable forest management, acting as an example of environmental product -based management.
- The need for product-oriented environmental policies in the pulp and paper sector requires careful assessments. The differences between the pulp and paper and electronics industries are evident: while the bulk of environmental impacts in the P&P sector has taken place during the extraction of raw materials and the production, the use phase is essential in the electronics sector. As long as fiber-based products are produced in the EU, the environmental impacts are probably easier to control directly through production. When production moves increasingly to other parts of the world, the functioning of the current systems, e.g. on recycling, might require product-based standards.
- A division of costs in a way that is generally accepted as fair is a problem within the collective producer organizations created for the management of extended producer responsibility. This can also weaken the link to product development if the greatest costs are not directed to those producers whose products ultimately account for the greatest costs in the waste management systems. The problems are similar within the EPR systems for packaging, but solutions will differ as the value of discarded products is different.
- The flexibility and predictability of legislative measures are often in conflict: e.g. directives that allow the Member States to take local conditions flexibly into account create also remarkable variation in the national systems, and thus more (administrative) work for the industry.
- Generally, environmental pressures from customers, environmental NGOs and policies will in the future focus more on the life-cycle impacts of products. This will highlight the better management of the product material content data as a way of avoiding business risks.

4.2 Barriers to innovation

In several cases there has been a very long time lag between the invention and its development into an innovation with a market. The main barriers that have been observed in the studied cases as slowing down environmental innovations include:

- market inertia;
- policy support, including regulatory systems, for traditional solutions;
- strong links between existing solutions and the whole production system;
- the lack of risk capital;
- market failures with respect to the environmental costs of energy and other raw materials;
- narrow perspective of actors and resistance to change; and
- lack or inefficient transfer of knowledge.

Existing technologies or processes create barriers for new alternative solutions through their dominant market share or because some existing policies that are in force ensure their profitability. This means that new, somewhat

uncertain, technology is less appealing to investors and companies renewing their production process. The strong market share of existing products and the related production equipment acts as a barrier, for instance, for the diffusion of wood-fiber-based CD and DVD cases and black liquor gasification. Whole existing systems can also hinder more radical innovation, because incrementally improved technologies often fit better into existing systems than the alternatives. Cooperation demonstrating the applicability of a new technology along the whole product value chain, such as in the Chemrec-Volvo cooperation, could break these barriers.

Profitability that is maintained by adopted policies is “artificial” in that it gives existing technology an unfair advantage. For instance, price support for existing fossil fuel-based and low-efficiency renewable energy technologies might prevent the emergence of more efficient alternatives. Agricultural support, in turn, could reduce the profitability of biofuels technology connected to the P&P industry by artificially lowering the cost of biofuels produced in agriculture.

4.3 Reducing barriers of innovation

Policies may create markets, as in the case of biofuels for transport, and can potentially break system lock-ins. Policies may also be able to correct market failures that show up as low prices of factors of production (such as energy). It is, however, important to ensure that competition is fair with respect to the desired properties of the technology. Moreover, policies should strive to avoid future lock-in situations. With this in mind, coordinated environmental, energy, industrial, transport and agricultural policies are important with respect to the different uses of biomass resources. If coordination fails, public policies may create or maintain technological dead ends.

Each environmental innovation case has been unique in how knowledge has been obtained and how it has contributed to the innovation, but there are also some common features. Cooperation between universities and different companies has been important in most cases. The companies involved are rarely limited to those producing P&P and may include the energy sector, technology manufacturers, electronics and the chemicals industry. In the future, cooperation could extend to many other sectors as well. In the development of bioenergy technologies, the P&P industry has often been the least interested and involved, which has slowed down the innovation process.

Although companies operate on international markets, some elements of the innovation processes have been clearly dependent on the national context. The cases show that the consortiums of actors involved in an innovation process have often been national endeavours despite efforts in some cases to attract partners from other countries. Public, national-level, R&D funding has been crucial in each case, as much of the funding for the P&P sector comes from Tekes in Finland and Mistra and the Swedish Energy Agency in Sweden.

Negotiating funding for an innovation project requires not only a technically good idea but connections and competence on the financial side. The potential difficulties in negotiating funding in some of the studied cases show the importance of public support on this level. The form and source of private funding has varied among the cases including options such as:

- Self-investments from the development company in the project
- Selling the ownership of the development company to different investors
- Acquiring investing companies to participate in the project
- Pre-selling licenses to technology-purchasing companies
- Lending money from banks and other sources

The cases demonstrate that there is no panacea for reducing barriers to innovation, and it takes both private and public actions to support environmental innovations.

4.4 Implications for Environmental Technologies Action Plan (ETAP)

The EU's Environmental Technologies Action Plan (ETAP) has led to several initiatives in its nine action areas (Section 1.3). It is clear that different businesses and product sectors have varying innovation dynamics, and therefore some actions are more relevant for selected sectors than others. Based on the study, we have commented below on the relevance and challenges of the ETAP actions from the point of view of the Nordic P&P sector. These findings may have similar implications on other low and medium technology (LMT) industries. The titles of the sub-sections are taken from the nine action areas of ETAP.

4.4.1 Increase and Focus R&D

First of all it is obvious from the cases that a sufficient educational infrastructure is a necessary precondition for successful long-term research. This has been evident in the Finnish and Swedish P&P sectors. Only then can R&D be increased and focused in a meaningful way in the sector.

R&D programs with environmental aims have been important sources of funding for environmental innovation in the P&P sector, especially as the companies have been characterized by low investments in R&D. The focusing of R&D on environmental technologies is important at all levels from national to the EU.

R&D programs have sometimes, for example in the CACTUS Programme funded by Tekes, directed a development initiated for other reasons to create also positive environmental impacts (Kivimaa and Mickwitz, 2006). Thus, an increasing emphasis on environmental technology research is likely to

be useful, provided that environmental technology is rather loosely defined as in ETAP, allowing opportunities for alternative technological paths to be explored.

Increasing emphasis on private sector R&D is important for creating commercial applications from public research. As an example, Finland's Science and Technology Policy Council has called for the establishment of five centers of excellence in the following areas: energy and the environment, metal products and mechanical engineering, the forest cluster, health and well-being, and information and communication industry and services. Following from this and the Forest-Based Sector Technology Platform, a new innovation company, Forest Cluster Ltd, was established in 2007 to initiate research and innovation programs and to channel research funds to selected focus areas (www.forestindustries.fi). The innovation company strengthens public-private networks in forest sector innovation, the owners comprising nine forest sector companies (pulp and paper, equipment, chemicals), four universities, the Technical Research Centre of Finland VTT and the Finnish Forest Research Institute (Metla). Funding for the company is provided by the owner companies, Tekes and the Academy of Finland.

Although our study has provided support for the notion that increased and focused R&D plays a key role in generating environmental innovations, the bioenergy cases illustrate that R&D funding is not as such a sufficient condition for successful innovations if markets do not exist or they are underdeveloped.

4.4.2 Technology Platforms

The Forest-Based Sector Technology Platform is not listed among the platforms described by ETAP as relevant for environmental technologies (ec.europa.eu/environment/etap), although the FTP research agenda lists several areas relevant from an environmental point of view. Its role as an environmental technology driver is expected to increase with the development of bioenergy and the possibilities to develop biorefineries. The FTP is likely to be central for future environmental innovation as accumulated experiences show the importance of research cooperation. The FTP has already been followed up by national-level actions, but it could be more efficiently linked to national ETAP initiatives and other technology platforms.

4.4.3 Environmental Technology Verification

There are difficulties in defining 'environmental technology' because a specific technology tends to have a variety of negative and positive environmental impacts (Kivimaa, 2007b). We found that environmental technology verification can be relevant in three different contexts: business to business, business to policy, and

business to customers. In the business to business dimension, Paper Profile, an environmental product declaration scheme for professional paper buyers, is a voluntary system developed and provided by leading paper producers presenting figures on essential environmental parameters in a uniformed way for specific products (www.paperprofile.com). This means that buyers have access to environmental information, but there is no external verifier who would provide ranking of different products. Yet standard rules exist on how to collect, calculate and present different pieces of information.

In the business to policy dimension, the Reference Document on Best Available Techniques acts as a kind verification of environmental process technologies in the pulp and paper sector. In business to consumers, the only environmental verification of products is based on eco-labels, such as the EU Flower and the Nordic Swan. There is potentially scope for additional standardized information to consumers, such as energy information for appliances. For example environmental loads such as CO₂ emissions could also be reported to consumers in a standardized way. This could provide information extending across different sectors, e.g. fiber-based, plastic-based and other packaging, allowing comparisons of the environmental performance of products serving the same purpose.

Verification in some format is definitely useful to promote the development of environmentally sounder technologies and products, but the format and application should be carefully considered. The danger of verification is that certain technological paths will be favored as different types of environmental impacts (e.g. emission vs. biodiversity) cannot be objectively compared. Environmental technology verification needs internationally accepted standards, yet the same technology may have different environmental impacts in different localities, e.g. depending on what technologies it will replace and in which conditions. The verifications also need to be revised on a regular basis, otherwise they might constitute a barrier for innovation. This is, however, easier in more stable industries such as pulp and paper than in very dynamic sectors such as electronics.

4.4.4 Performance targets

Performance targets and performance-based regulation have been found to influence environmental innovation in the P&P sector. Non-binding targets may provide indication of future policies and therefore promote inventions in and the development of new technologies, often at least partly resulting from anticipating future environmental policies. Binding targets better aid the commercialization and diffusion of innovations. For example, both recovery boilers reducing air emissions and more energy-efficient paper manufacture were researched in Finnish technology programs in the 1980s and early 1990s. The diffusion of new recovery boilers, and subsequently the reduction of air emissions in the P&P sector, has been extensive, following binding limits for reduced air emissions in individual mills (Kivimaa and Mickwitz, 2004). At the same time, improvements in actual energy efficiency have been fairly modest and they have mainly been promoted by voluntary agreements.

In connection with targets, it is important to notice that too speedy introduction of binding targets may hamper innovation if more advanced technologies are not yet ready for commercialization and companies must adopt existing solutions. Therefore, the timing of, first, non-binding and, later, binding targets, and their gradual tightening is crucial. In addition environmental policy targets should always be combined with public R&D actions to strengthen the policy signals sent to companies, as it has been found that environmental policies and technology policies have combined effects on environmental innovations in the P&P sector (e.g. Kivimaa and Mickwitz, 2004) and technologies need years of development before they are ready for commercial applications. The biogasification technologies of the P&P sector are a case in point. Without decades of development work, the technologies would not be ready to respond to the EU biofuels directive. Other challenges related to target setting include agreeing on targets that are ambitious enough to promote innovation over existing technologies and flexible for the testing of new solutions (e.g. Kivimaa, 2007a). For instance, a target for the reduction of CO₂ emissions from transport would offer more flexibility of different types of technological solutions combating climate change than targets for the share of biofuels in transport, even if the biofuels target has been successful in supporting certain types of environmental innovation (Kivimaa, 2008).

4.4.5 Mobilization of financing

Public and private funding and loans have been crucial in the research, development and demonstration phases of P&P-sector environmental innovations. A variety of funding mechanisms and easy access to them is important. Public actors can also act as guarantee providers to facilitate speedy demonstration of new technologies (see example in 3.4). Private organizations need motivation to invest in environmental innovation, e.g. through consistent, long-term policies. Globalization has increased the P&P sector's access to international private funding, and therefore national-level public funding would better support small start-up companies and their innovation ventures.

4.4.6 Market-based instruments

Market-based instruments, such as environmental tax incentives, have not been directly relevant for many of the environmental innovations of the P&P sector, while environmental regulations have played a significant role. This may be explained by low financial incentives given by the instruments (e.g. Finnish energy tax) or their too recent introduction (e.g. CO₂ trading) (Kivimaa, 2008). The challenge of the market-based instruments is to reach a decision by which the instruments provide strong enough incentives that promote environmental innovation and reduce environmental externalities.

4.4.7 Green public procurement

Green public procurement has had low impact on the environmental innovations studied in this report. There is potential for green public procurement in this sector, especially in relation to the development of specific products with environmental labels. For biofuels, public transport can offer possibilities to test and develop new fuel infrastructure. The recent report of the ETAP (CEC, 2007: 10) states that "systematic and coordinated activity on demand-side is needed" and for example Edler and Georgiou (2007) have recently argued that public procurement has had more positive effects on innovation than R&D public subsidies.

Potential problems regarding the innovation support created by green public procurement arise from a certain rigidity of public systems to change (as innovation could require a rapid renewal of contracts), lack of available expertise on the total environmental impacts of product chains, and value judgments regarding the comparison of different environmental impacts (see verification of environmental technologies). Nevertheless, at the moment, there are plenty of expectations of positive effects from public procurement in different policy areas. This can lead to complicated and costly administrative processes, as all these aspects have to be taken into account and the decisions made have to be reasoned publicly. This means that public decision making is often more complicated and thus less efficient than private (Wilson 1989, 315ff).

4.4.8 Awareness raising and training

New opportunities for environmental innovation lie in inter-sectoral cooperation, e.g. between the P&P industry and the automotive and electronics industries. Raising awareness among the individual actors of the P&P sector about opportunities from crossing sectoral boundaries could be extremely useful for environmental innovation. Moreover, know-how and knowledge generated from a variety of sources and access to knowledge is crucial for environmental innovation processes (Section 3.2). A thorough integration of environmental issues into different knowledge processes (public & company R&D and their evaluation systems) would benefit environmental innovation. In addition, the maintenance and focus of national education systems (as noted in 4.2.1) is relevant.

4.4.9 Supporting eco-technologies in developing countries

In some cases, especially for environmental technologies created by SMEs, the first markets have been found in the developing countries (Kivimaa, 2008). P&P production has rapidly expanded in the developing countries allowing for more flexibility to test new technologies, but the availability of funds may restrict the renewal of technology. Support for environmental technologies in developing countries can significantly support environmental innovation and technological

change also on a global level. It also reduces the market risks for those investing in innovation by supporting the expansion of the market for new environmentally friendly technologies.

4.4.10 Further development of the ETAP

The discussions and conclusion of the sector workshop organized in Oslo in March 2007 supported many of the activities that form the core of the ETAP. In addition, a number of possible actions that do not exactly coincide with any of the present specific ETAP activities were identified. These include:

- 1) Novel form of financial support such as support to the users of innovation to reduce the initial additional costs that arise when new products do not fit into the existing system and support for systems transformation to remove lock-in situations;
- 2) Greater focus on system innovation by looking at product/service chains and the impacts along their life cycles;
- 3) Stronger emphasis on the consistency of policies, e.g. regarding energy and environment in order to contribute to systemic rather than piecemeal changes.
- 4) International cross-sectoral sensing, i.e. identifying large areas for test markets (some of this could be realized through technology platforms);
- 5) Making lobbying transparent in order to ensure a “politically level playing field” for different technological solutions;

Further development of ETAP should fully recognize that knowledge originates from different public and private sources. As the diffusion of environmental knowledge and environmental policy signals is crucial, ETAP can, by having a clear focus, provide stronger incentives for environmental innovations than the more general, horizontal innovation policies. The discussion on horizontal innovation policy relates to policies embedded in a broader socio-economic context (cf. Lundvall et al., 2002; Pelkonen, 2006).

While ETAP has proposed a variety of actions in support of environmental innovation, attention should also be focused on the evaluation of the measures and in particular on the identification and reduction of innovation barriers in different countries and sectors and in the EU as a whole. For instance, the existing packaging and packaging waste directive sets completely different recycling requirements for plastic and fiber packaging. The problems caused by existing regulatory systems are not fully addressed by ETAP. There are also a number of areas in which the measures included in the ETAP may contribute to the present inertia rather than serve to overcome it (Table 4.1, potential problems indicated in italics). For example, the strong links between existing solutions and the whole production system can be reinforced by performance targets

⁸ CEC (2007) states “Evidence shows that well designed legislation does act as a driver for innovation and environmental technologies, which in turn can help companies in significantly reducing costs” and “Systematic and coordinated activity on the demand-side is needed.”

that have been developed for present production systems. In a similar way processes for environmental technology verification can prove to be a barrier for innovative solutions, if the adopted criteria for verification do not match those of a radical new invention.

Future development of the ETAP should recognize the possibility of unintended negative side effects of the measures that at first sight appear to be purely beneficial. To reduce the risks of such unwanted side effects the measures should take a broad view and pay particular attention to system effects and innovations. In addition, the policies and measures should be subjected to in-depth evaluations that can contribute to social learning processes and, thereby, also identify innovative policy opportunities. Initially, much of the focus was on the technological side (for example Galleja et al., 2004) coupled with rather superficial analyses of how policies and policy instruments affect the actors and their innovative capabilities. The most recent report recognizes the policy aspect and the need for demand-side approaches at the level of policy.⁸ There is, however, still a need to systematically analyze the barriers to innovation as well as the possibilities to introduce innovation drivers in existing regulatory systems.

Table 4.1 The links between the ETAP Actions and the identified barriers: possible advantages and risks

ETAP Action	Market inertia;	Policy support, including regulatory systems, for traditional solutions	Strong links between existing solutions and the whole production system;	The lack of risk capital	Market failures with respect to the environmental costs of energy and other raw materials	Narrow perspective of actors and resistance to change	Lack or inefficient transfer of knowledge
Increase and focus R&D		Need for analyses of policy implications of novel technological solutions	Can highlight problems		Can highlight problems	New perspectives	Improving knowledge transfer through designed networking
Technology platforms		New insights and feedback to policy development; <i>some risks for corporatism</i>	May offer forums for debate of transformations <i>but may also cement traditional thinking and solutions</i>	Can attract risk capital		May offer forums for debate of transformations <i>but may also cement traditional thinking and solutions</i>	Improving knowledge transfer through institutionalised networking
Environmental technology verification	New reference information can lower market barriers	<i>May strengthen role of traditional solutions and thus hinder removal of barriers</i>		Can reduce investment risks and thereby attract capital		New reference information can overcome part of resistance <i>but may also increase resistance to change</i>	Systematised information is easier to transfer
Performance targets	Prepares grounds for developing markets	May contribute to reassessments, <i>but can also be conservative, favouring incremental rather than radical change</i>	May contribute to reassessments, <i>but can also be conservative, favouring incremental rather than radical change</i>	Can reduce risks by indicating developing markets	Can highlight solutions	Can overcome some resistance by fostering debate	
Mobilisation of financing (grants and loans)			Can offer opportunities for change, <i>but rigid criteria may favour existing solutions</i>	Direct reduction of problem	Can correct for certain market failures	May contribute to rethinking	
Market-based instruments	May also support development of technological market	Can reduce link between specific solutions and policy	May contribute to rethinking		Can correct for certain market failures		
Green public procurement	May create or develop specific markets	May support new solutions, <i>but too rigid and slowly changing procurement criteria may also become a barrier</i>		Can reduce risks by indicating developing markets		May support new solutions, <i>but too rigid and slowly changing procurement criteria may also become a barrier</i>	Facilitates information transfer
Awareness raising and training	Prepares grounds for developing markets	May contribute to reassessments	May contribute to rethinking	Can reduce risks by indicating developing markets	Can initiate considerations of market failures	Can overcome some resistance by fostering debate	Facilitates information transfer
Supporting eco-technologies in developing countries and promoting foreign investment	May support specific markets	May contribute to regulatory development by demonstrating possibilities to combat pollution	May support system transformation, <i>but may also maintain existing solutions</i>	Can reduce risks by developing markets	Can correct for certain market failures		Can greatly enhance knowledge transfer, <i>risk lack of context sensitivity</i>

National Innovation Systems still often support the networks through which innovations are created in the P&P sector, but the formation of innovation markets is increasingly dependent on international developments (see also Kivimaa and Kautto, 2007). EU policies, e.g. the biofuels directive, have increasingly created the final impetus for some environmental innovations. While EU policies may create a larger market for potential innovations, the slowness and rigidity of the larger political system may also slow down innovation compared to more local or national-level policies. Thus certain activities supporting environmental innovation can and should be maintained at all levels from local/regional to national and EU. These include focusing R&D on environmental technologies, setting environmental performance targets, mobilization of financing, green public procurement and awareness raising and training.

Although the EU can create more incentives for larger companies to innovate through larger market and funding potential, local initiatives are more flexible for the change needed to spur innovation and more accessible for smaller actors. Our findings on environmental innovation in the P&P industry illustrate the importance of both national and EU standards. Other studies in the marine engine sector have shown that even local market-based instruments can promote innovation that spreads globally (Hyvättinen and Hildén, 2004).

5. Conclusions

Supporting environmental innovations requires consistent efforts that combine and coordinate innovation and environmental policies. ETAP is a good starting point for creating a policy mix for environmental innovation. Innovation support requires drivers that create the base for innovations, factors such as education and basic and applied research, and overall environmental targets that the improvements are aimed at. After the basis is created, more binding requirements are needed to promote the adoption and use of the generated innovations. In addition, public-private partnerships, such as the Forest-Based Sector Technology Platform and the Forest Cluster Ltd, are important in creating visions and action for future innovation.

Innovations are still strongly linked with national innovation systems (NIS) at least in the P&P sector. An extensive NIS, including public higher education and research, can create necessary preconditions for innovation even in low-R&D investment sectors, such as the P&P sector. Yet building up a sectorally oriented NIS, with significant investments in the education and research related to a specific sector takes decades, and is thus not suitable for supporting innovation in every sector and in every location. Still the NIS overall creates some prerequisites for market-based pull for innovations. As many of the technologies take years to develop, knowledge and near-commercialization inventions need to be available to respond to new market demands, whether they are caused by increasing electricity price or new regulatory requirements. The market pull is, by contrast, increasingly dependent on international development in commodity markets or EU policies. Therefore, ETAP actions need to consider the continuum from national to international as well as various forms of public-private partnerships and participatory processes.

The Strategic Research Agenda of the EU's Forest-Based Sector Technology Platform (2006) is an important document highlighting future innovation activities in the European P&P industry. The forest industries in Finland and Sweden have both published their national forest-based research agendas following the technology platform, highlighting fairly similar issues for innovation (Finnish Forest Industries Federation 2006; NRA 2006). Thus the FTP is a tool that combines national and EU efforts in supporting innovation in the forest sector.

The Forest-Based Sector Technology Platform emphasizes environmental issues and aims to turn the threats and challenges facing the forest sector, including the climate change issues, into opportunities. While many environmental improvements have been made in the past to reduce water and air emissions from the forest industry, innovations in the forest sector still have the potential to provide environmental improvements in the form of replacing less harmful chemicals, increasing renewable energy in transport

and electricity production, saving energy, providing recyclable products for new product markets, and contributing to waste management along product value chains in other sectors. ETAP should not forget the less likely sources of environmental innovation emerging out of inter-sectoral cooperation.

In addition to highlighting the connection between NIS, internationalizing markets and EU policy-created markets, the study has identified needs for future research. There appears to be clear differences in the innovation dynamics and policy influence between low and high technology sectors, such as pulp and paper and electronics. A more thorough comparison of environmental innovation in low, medium and high technology sectors could tell us more about what kind of policies are needed. Product-related policies have had relatively little influence on the P&P sector, and the future potential of Integrated Product Policy to influence environmental innovation in this sector is still an open question. Furthermore, the links between IPP and ETAP could be subjected to further analysis.

The particular role of public policies and policy intervention needs to be considered and developed further. Apart from the maintenance of general environmentally conscious high-quality education with a high degree of environmental awareness, we have identified the following public roles to be particularly significant:

- Markets created or enforced by environmental policies through regulations or market-based instruments have been crucial for those innovations that provide significant benefits for environmental protection but that at least initially appear to be technologically uncertain or significantly different from the current production and consumption systems.
- The public sector can clearly influence the diffusion of environmental objectives into the knowledge creation processes through criteria for research funding, development of specific educational curricula, supporting networks and by creating or enhancing markets that can attract information from different business sectors.
- Consistent long-term public policies can reduce the non-technical risks and increase the expected benefit of environmental innovations by creating or contributing to developing markets.
- Public funding has contributed to risk funding, in particular in the early phases of company development.

By focusing on these areas and by developing specific measures within these areas the public sector is likely to significantly contribute to environmental innovations also in the future. The measures may also develop awareness in the sector itself that it needs to increase significantly its R&D activities in order to make significant contributions to novel solutions in the spirit of the Lisbon Strategy.

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Sammandrag

Politiska initiativ såsom Lissabonstrategin har betonat miljöinnovationers centrala betydelse då det gäller att lösa miljöproblem och de har strävat till att främja miljöinnovationer på olika sätt. Denna rapport analyserar ett urval miljöbefrämjande teknologiska innovationer och deras förhållande till samhälleliga och ekonomiska drivkrafter, i synnerhet offentlig politik. Studien bygger på empiriskt material hämtat ur den nordiska massa- och pappersindustrin. Rapporten diskuterar också åtgärderna i EU:s miljöhandlingsplan ETAP ur massa- och pappersindustrins synvinkel.

Studien bygger på dokumentanalys, intervjuer, diskussioner vid arbetsmöten samt kommentarer av representanter för den nordisk skogssektorn. De enskilda fallstudierna omfattar användningen av biprodukter för energiproduktion, nya produkter i nyckelaffärsområden och nya värdekedjor.

Uppfinningarna och innovationerna som analyserats i studien pekar på några centrala drivkrafter och hinder för miljöinnovationer. Viktiga drivkrafter innefattar utvecklingen av en marknad för miljöorienterade innovationer – ofta stödd av miljöpolitik och konsumenttryck - tillgång till ett brett fält av relevant kunskap, miljöorienterad offentlig och privat finansiering samt nya nätverk av aktörer. Tröghet på marknaderna, politikbaserat stöd för traditionella lösningar, starka bindningar mellan traditionella lösningar och hela produktionssystemet, brist på riskkapital, marknadsfel i fråga miljökostnader för energin och andra råvaror, vissa aktörers snäva perspektiv och motstånd mot förändringar samt ineffektiv överföring av kunskap har varit betydande hinder som bromsat upp utvecklingen av miljöinnovationer. De olika exemplen visar att olika hinder och drivkrafter kan spela in, men till exempel utvecklingen av bioenergiteknologin visar att inte bara den absoluta styrkan utan också förhållandet mellan pådrivande krafter och hinder är av stor betydelse.

Offentlig politik har inte varit avgörande i varje enskilt fall men kan skapa ett ramverk som stöder miljöinnovationer och samtidigt hjälpa till att identifiera bristande miljöeffektivitet. Den offentliga politiken har påverkat miljöinnovationer inom massa- och pappersindustrin genom allmänt stöd till forskning och utveckling, delfinansiering av utvecklingsprojekt samt genom att skapa förutsättningar för samarbete mellan offentliga och privata aktörer. Investeringsstöd för demonstrationsprojekt och stöd för utveckling av företagsfinansiering har även påverkat innovationerna. Därtill har den offentliga politiken skapat eller stärkt marknader för miljöinnovationer som kunnat konkurrera i fråga om positiva miljöeffekter.

Även om innovationsmarknaderna i allt högre grad är beroende av internationell utveckling och miljöpolitiken påverkas starkt av EU ligger grunden för miljöinnovationerna inom den nordiska massa- och pappersindustrin i de

nationella innovationssystemen. Den nordiska utbildningspolitiken som har skapat ett starkt tekniskt kunnande har varit avgörande då det gällt att utveckla den bas som behövs för att ett mer direkt stöd till innovationer skall kunna fungera.

För miljöpolitiken och ETAP är möjligheterna att skapa eller stärka ”gröna” marknader med hjälp av offentlig politik viktiga. Framgången för marknader som skapats av politik är emellertid i avgörande grad beroende av andra parallella eller påföljande marknadsförändringar såsom priset på råvaror eller energi, vilka stärker utvecklingen mot bättre miljöeffektivitet. Miljöpolitiken klarar sällan ensam av att tvinga fram innovationer.

Studien har genomförts vid Finlands miljöcentral och är en del av forskningsprojektet Green Markets and Cleaner Technologies - Leading Nordic Innovation and Technological Potential for Future (GMCT, 2006-2007) som genomförts i samarbete forskare från IIIIE vid Lunds universitet, universitetet i Ålborg och Danmarks Tekniske Universitet. Projektet finansierades av arbetsgruppen för integrerad produktpolitik under Nordiska Ministerrådet.

Yhteenveto

Politiikka-aloitteet, kuten Lissabonin strategia, ovat painottaneet ympäristöinnovaatioiden tärkeyttä monien ympäristöongelmien keskeisenä ratkaisuna ja pyrkineet monin tavoin niiden edistämiseen. Tässä raportissa analysoidaan pohjoismaisesta massa- ja paperiteollisuusteollisuudesta kootun empiirisen aineiston perusteella ympäristöinnovaatioita ja niiden suhdetta erilaisiin yhteiskunnallisiin ja taloudellisiin tekijöihin, erityisesti julkisiin toimintapolitiikkoihin. Lisäksi raportissa pohditaan EY:n komission Ympäristöteknologian toimintaohjelman (ETAP) ehdotuksia massa- ja paperiteollisuuden näkökulmasta. Tutkimus perustuu dokumenttianalyysille, haastatteluille, keskusteluille hankkeen työpajoissa sekä pohjoismaisen metsäsektorin edustajien kommenteille. Tutkitut tapaukset liittyvät tuotannon sivutuotteiden energiahyödyntämiseen, uusiin tuotteisiin ydintoimialueella ja uusiin arvoketjuihin.

Raportissa analysoitujen keksintöjen ja innovaatioiden perusteella voidaan tunnistaa ympäristöinnovaatioiden syntyä keskeisesti edistäviä ja estäviä tekijöitä. Keskeisiä innovaatioiden syntyä edistäviä tekijöitä ovat muun muassa politiikan luomat tai asiakaspaineista syntyneet innovaatioita tukevat markkinat, saatavilla oleva monipuolinen tieto, ympäristöperusteinen julkinen ja yksityinen rahoitus sekä toimijoiden väliset uudet verkostot. Keskeisinä ympäristöinnovaatioiden syntyä estävinä seikkoina tulivat esiin markkinoiden inertia, politiikan tuki vallitseville ratkaisuille, valitsevien ratkaisujen kytkeytyminen koko tuotantojärjestelmään, riskipääoman puute, markkinahäiriöt energian ja raaka-aineiden käytön ympäristövaikutusten näkymisessä hinnoissa, joidenkin toimijoiden kapea näkökulma ja muutosvastaisuus sekä huono tiedonkulku. Tapaukset ilmentävät eri kannusteiden ja esteiden tärkeyttä, mutta esimerkiksi bioenergiaan pohjoismaisessa massa- ja paperiteollisuudessa liittyvät tapaukset osoittavat myös näiden kannusteiden ja esteiden keskinäisten suhteiden suuren merkityksen.

Vaikka politiikkatoimenpiteet eivät olekaan kaikissa tutkituissa tapauksissa olleet tärkeitä, voivat ne tukea ympäristöinnovaatiota ja auttaa tehottomuuksien löytämisessä. Julkiset toimintapolitiikat ovat vaikuttaneet massa- ja paperiteollisuuden ympäristöinnovaatioihin suoraan julkisena T&K-tukena, kehityshankkeiden rahoituksena, yksityisten ja julkisten toimijoiden väliseen yhteistyöhön kannustamisena, investointitukena ja apuna sen löytämisessä demonstraatiohankkeille, sekä luomalla tai vahvistamalla markkinoita ympäristöinnovaatioille ja kannustamalla näiden väliseen kilpailuun.

Vaikka markkinoiden muodostuminen innovaatioille onkin enenevässä määrin kytköksissä kansainväliseen kehitykseen ja ympäristöpolitiikan muotoilu tapahtuu pääosin EU-tasolla, ympäristöinnovaatioilla on Pohjoismaisessa massa- ja paperiteollisuudessa selkeä yhteys kansallisiin

innovaatiojärjestelmiin (national innovation systems, NIS). Suuria teknisen tietämyksen kokonaisuuksia luonut pohjoismainen koulutuspolitiikka on monessa suhteessa ollut perustana suuremmalle innovaatiotuelle.

Ympäristöpolitiikkojen ja ETAP:n kehityksen kannalta vihreiden markkinoiden luominen ja vahvistaminen ovat oleellisia. Toimintapolitiikkojen luomien markkinoiden onnistuminen on kuitenkin pitkälti riippuvainen samanaikaisista tai sitä seuraavista muutoksista esimerkiksi energian ja raaka-aineiden hinnoissa, joilla on samansuuntainen vaikutus ympäristöasioiden huomioon ottamiseen. Ympäristöpolitiikka on vain harvoin yksin riittävä kannuste innovaatioille.

Raportti on laadittu Suomen ympäristökeskuksessa (SYKE) ja se on osa SYKEN yhdessä Lundin yliopiston IIEEE-instituutin, Aalborgin yliopiston ja Tanskan teknillisen yliopiston kanssa toteuttamaa Green Markets and Cleaner Technologies - Leading Nordic Innovation and Technological Potential for Future (GMCT, 2006-2007) –tutkimushanketta. Hankkeen rahoittajana oli Pohjoismaisen ministerineuvoston Yhdennetyn tuotepolitiikan ryhmä.

Appendix I: Case-study framework

QUESTIONS FOR INNOVATION CASES		
<p>Can you describe how the technology has been developed? Why did the process start? What were the main driving forces to take this further? Who were the main participants? With whom did you work with? Which were the key milestones?</p>		
Research questions for case studies	Sub-questions	CHECKLIST FOR Interviews
Knowledge - pools, access, roles of different types of knowledge?	Generation and diffusion of knowledge through public mechanisms?	Participation in public R&D programmes?
		Basic knowledge from publicly funded R&D as contributing to the innovation?
		Co-operation with universities and public research institutes?
		Signals from public policy (e.g., environmental or technology policy) affecting the development?
	Generation and diffusion of knowledge within the company?	Co-operation between departments (e.g., product development and environmental management)?
		Investment in creating new ideas and innovations (e.g. innovation centers, own R&D)?
		Environmental training of people involved in R&D issues?
	Generation and diffusion of knowledge through inter-organisational cooperation?	Different actors involved in idea generation, R&D, pilot testing and diffusion of the innovation?
		Closeness of cooperation with other organizations?
		Role of inter-company R&D forums?
Standards, criteria and institutional rules?	Role of public policies as drivers for innovation or its diffusion?	Technical standards?
		Environmental policies (e.g. emissions limits, recycling requirements)?
		Health policies?
		Aims to modify the rules of the game (e.g. influence the public policy?) If yes, as a company or through an association?
	Role of intra-organizational standards and rules?	Environmental standards in intra-organizational rules and procedures for R&D?
	Role of national and international inter-organisational standards and standard setting?	Market standards (e.g., product and electricity markets)?
		Technical standards?
		Environmental standards (e.g., ecolabels, forest certification)?
		Participation in the standardization work?
Funding and financial resources?	Public funding?	Subsidies? R&D funding? Tax exemptions? Public risk capital? Public venture capital?
	Corporate funding?	Innovation centers? Own R&D project funding? Establishing a subsidiary company around the innovation?
	Other private funding?	Venture capital? Bank loans? Stock markets? Collaboration with other companies?
Actors & Networks	Public actors	Policy makers? Universities? Research institutes? Public-owned funding institutions?
	Intraorganizational	Environmental unit? R&D unit? Product development unit? Marketing unit?
	Private actors	Customers? Competitors?