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Making or breaking environmental innovation? Technological change and innovation markets in the pulp and paper industry

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ABSTRACT

Recent academic discussions emphasize internationalizing systems for knowledge generation and innovation. Yet much of academic literature is focused on national innovation systems (NIS). In this study, the crucial factors for environmental innovation are analyzed in a transforming industry sector, the Nordic pulp and paper industry, focusing on bioenergy technologies in pulp mills and on new products from fiber. The analysis examines the role of internationally changing market conditions versus NIS for innovation in this sector.

While NIS still supports the networks through which innovations are created in the sector, the formation of innovation markets is increasingly dependent on international developments. Environmental innovation is most likely when momentum is created by simultaneous changes in both private and policy-created markets. Environmental policies, increasingly originating at EU-level, have added the final impetus for bioenergy technologies, while for new products the policy effect has been smaller. For environmental innovation, environmental policies can make or break the final development.

Keywords: environmental innovation, innovation markets, environmental policy, pulp and paper industry

1. Introduction

Technological innovations with potential for reduced environmental impacts, i.e. environmental innovations, have often been identified as key solutions to many environmental problems, such as climate change. Recent discussions on the EU-level, including the Environmental Technologies Action Plan (Commission of the European Communities 2004) and the Communication on Integrated Product Policy (Commission of the European Communities 2003), have highlighted the importance of creating environmental innovations. Similarly sectoral efforts, such as the EU-level Forest-Based Sector Technology Platform (2006) and the national strategic forest-based research agendas of the Nordic countries, address innovation with potential for environmental benefits. The discussion often deals with finding the right ways to promote these innovations.

The variety of factors affecting the innovation process have often been conceived as forming an innovation system. The narrow definition of an innovation system sees it composed of those institutions which deliberately promote the acquisition and dissemination of knowledge, such as the formal R&D system and technical education (Freeman 1995, 2002). The broader approach recognises that these narrow institutions are embedded in a wider socio-economic system in which political and cultural, market and non-market factors influence the rate and success of innovation activities (Freeman 2002; Meeus and Edquist 2006). Regulatory bodies and public and private investments in supporting infrastructures are integral components of innovation systems (Kuhlmann and Shapira 2006). Environmental policies and regulation have been specifically

mentioned to contribute to innovation systems (e.g., Lundvall 1992; Chaminade and Edquist 2006) but the specificities how environmental policies function have not usually been explored in the NIS literature.

The connection between environmental policies and innovations has received attention, revealing sometimes rather conflicting results (e.g., Ashford 1996; Kemp 1997, 2000; Cleff and Rennings 1999; Norberg-Bohm 1999). Some scholars have found that environmental policies can indeed result in innovations (e.g., Hemmelskamp 1997; Norberg-Bohm 1999; Kemp 2000; Becker and Englmann 2005), while others have found them to have also negative effects (e.g., Jaffe et al. 2003). Studies examining environmental innovations in the pulp and paper sector have provided more detailed results regarding the influence of environmental regulation on innovation, but the importance of other factors has been rarely mentioned (Laestadius 1998; Saether 2000; Harrison 2002). The inconsistent and context specific results of the environmental innovation studies indicate that the relationship between environmental policies and innovation cannot purely be explained based on the type of policies in question.

The Green Markets and Cleaner Technologies project has examined how recent technological inventions and innovations with environmental benefits have developed in the Nordic pulp and paper industry, exploring a variety of drivers for the developments. This paper presents some results from that study, focusing on how environmental policies may create markets for innovations in the context of other market factors. Thus, we aim to shed light on the kind of contexts, where environmental policies may have a positive influence on innovation. This is of interest, because still very little is known

about what motivates some companies to go beyond compliance in responding to environmental policies (Gunningham et al. 2003) and about the formation of new markets for innovation (Chaminade and Edquist 2006).

The Nordic pulp and paper industry is characterized by strong national importance especially in Finland and Sweden, internationalizing and consolidating companies, and process innovation. It has been a low investor in research and development in the past decades and fairly reluctant to become heavily involved with innovations outside its core business areas. The recent trends for globalizing markets, lowering price for paper products and speedier diffusion of information have changed the conditions where the pulp and paper companies operate and has forced the sector to seek opportunities to expand to new market areas and product value chains (see Forest-Based Sector Technology Platform 2006). Focusing on bioenergy technologies in pulp mills and on new products from fibre, the study explores the drivers and barriers for environmental innovation. The dynamics underlying innovation are compared to previous innovation cases from the 1980s and 1990s.

We will first present a background for environmental innovations in the Nordic pulp and paper industry. Section 3 presents the empirical cases of this study, and Section 4 explores the results on the development of environmental innovations from a market perspective. In Section 5, the results are discussed from the perspectives of internationalisation of markets and policies. Section 6 concludes the paper.

2. Environmental innovation and the Nordic pulp and paper industry

Berkhout (2005) has characterized innovation and environmental performance in technological regimes as unfolding dynamically out of the interaction of four different types of innovation - abatement, process innovations, product innovations and infrastructural changes. Our innovation case studies from the pulp and paper industry focus on two of these types: process and product innovations, in short referred to as "technological innovations".

Environmental improvements in the sector involve manufacturing processes, products and emissions treatment. These are connected, because some new products require also renewed production processes and improved 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 the types of environmental improvements they cover:

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

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

Innovations in the pulp and paper 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). For example recycling processes may increase energy consumption. The diffusion of innovations is always a prerequisite to actually benefit from the environmental improvement possibilities that new products and processes entail.

The over 100-year history of the Nordic pulp and paper 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. Environmental problems began to draw broad public attention during the second half of the 19th century (Andersen 1999; Sæther 2000). First, deteriorating water quality was addressed and, later, air quality. This started a period of decades where the Nordic pulp and paper industry has been innovating to

achieve environmental improvements, first, in water emissions and, later, also in air emissions and resource efficiency.

Despite rapid increases in production levels, the absolute water emissions have been significantly reduced due to a decoupling between production and water emissions in the 1970s. The first improvements in the Nordic countries were made following water regulation (e.g., Harrison 2002; Hildén et al. 2002). Through internationalisation (Moen and Lilja 2001; Donner-Amnell 2004), the central European customer demands have also resulted in environmental improvements, for example, in abolishing the use of chlorine in pulping, further reducing the industrial water emissions. During the last two and a half decades, the relative use of raw wood has reduced by a quarter per tonne of paper produced. The resource efficiency improvements have been responses to the goals to improve cost-efficiency, but increases in the total production have still increased the absolute use of wood. It has been argued that while most companies have responded to the environmental challenge, the ecological modernization of production remains partial because energy and forest use have continued to rise (Lehtinen et al. 2004).

Environmental innovation in the Nordic pulp and paper industry has mostly focused on production processes. This is partly because environmental regulation and customer pressures have been targeting mainly production, not products (Kivimaa 2007). For the legislator the regulation of environmental impacts through products is extremely demanding and potentially both economically and environmentally hazardous. This is because products and product development are in the core of business and product related information may only be obtained from companies. (Kautto forthcoming.) In the

product side environmental developments have largely focused on the use of recycled fibres, although paper and packaging companies have also aimed to develop lighter and more durable products for decades (e.g., Kautto et al. 2002). At the same time product innovation in general has received increasing attention. However, as the bulk of environmental impacts in the pulp and paper sector take place during the production (cf. e.g., electronics), the possibilities for environmental improvements in the sector have been greater through processes.

3. Empirical cases for the study

Our focus is on recent innovations and inventions offering potential for improved resource-efficiency and reduced use of fossil fuels. To select the innovation cases trade journal articles from *Pulp and Paper International* and *Paper and Timber* were reviewed between the years 2000-2006. An email questionnaire was also sent to eleven P&P experts in Finland, Sweden, Norway and Denmark to solicit their views. Based on five replies and journal information, seven cases representing three commercialized innovations and four technologies in demonstration were selected (Table 1).

The cases are based on a combination of interview and written sources, including 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, a case study framework was developed to be used in forming interview questions and analyzing the findings. An opportunity to comment the initial

findings were offered to the pulp and paper industry experts in a workshop in March 2007.

Table 1 here

4. A market perspective on the development of environmental innovations in the Nordic pulp and paper industry

4.1. Results from the case studies

The findings from the case studies illustrate various factors that have been important in different stages of the developments: knowledge inputs from different sources, entrepreneurial individuals, networks of cooperative actors, public provisions for R&D, public policies and market changes among others. These are similar findings to previous research on the emergence and development of innovations. In this paper, we focus solely on the market and cost factors of the case studies, because these findings in our opinion add most to the discussions on innovation market formation and on how environmental policies influence innovations.

The development of a new type of pulp mill, *the BCTMP mill*, started from awareness within M-real, a Finnish pulp and paper manufacturer, that the company's existing pulp mills were getting older and producing too little pulp too inefficiently. The main aims were to increase the capacity of mechanical pulp production, 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 assumptions were made that energy prices will increase in the future. Later customer needs and M-real's long-term goal to produce lighter weight paper that maintained 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 fibre. Paper with reduced weight offers cost benefits for the customers e.g., due to lower transportation costs.

Searches for mill-level efficiency improvements and 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 side-products, e.g., energy products, in addition to 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 currently the oil and electricity prices are high, the ideas behind the three cases of biorefinery related technologies have 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.

A strong driving force for STFI, a Swedish research and consulting company, developing *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 50-70percent of the investment costs required to rebuild a recovery boiler. In 1996, when the development leading to LignoBoost began, research in 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. The current high oil price has increased investors' interest in LignoBoost, and two energy companies have been actively involved and licences for the technology have been pre-bought by interested customers.

Gasification has for 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 perceived by the P&P industry hindered further developments. The electricity price was low in the Nordic Power Market and a fairly efficient already existing alternative, the recovery boiler, offered a competitive alternative.

Chemrec's process of developing *black liquor gasification* began in the late 1980s in Sweden when an engineer, with a background in the P&P industry, thought 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 manufacturing P&P equipment and the company Chemrec was established in 1987. The ownership of Chemrec changed several times in the course of 20 years and the development of black liquor gasification was hindered, first, by technical and financial difficulties and, later, due to a lack of interest from the pulp and paper industry. The financial and administrative support from the Swedish Energy Agency was crucial when the interest of private investors was low.

Wider interest among the P&P companies was not woken up 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 required that the member states achieve a minimum proportion of 2 percent of biofuels in the energy content of transport fuels by 31 December 2005 and 5.75 percent by 31 December 2010. Thus it created a market for new technology, while the increased price of oil fuelled 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 the technical director of Chemrec invented to combine syngas and pulp production to produce transport fuels (DME). Another economic driver was the energy tax reliefs for renewable fuels in Sweden that make the net payback time quicker. DME costs the same to produce as diesel but environmental charges and taxes do not have to be included in its selling price.

Following the Directive, Chemrec created cooperation with Volvo who had developed a truck motor using DME as fuel. Volvo was interested to cooperate because they anticipated a future with stringent requirements for emissions from heavy duty diesel

engines. Climate change, projected availability of energy sources and energy security acted as key drivers for future market developments in transport fuels. Volvo is starting the commercial production of DME engines in 2011 and wants to have a big demonstration project from Chemrec for having the fuel commercially available. From 2007 Volvo Technology Transfer has been a co-owner of Chemrec.

The EU Biofuels Directive together with security of supply concerns and increasing price of oil have also driven technological development for producing transport fuels from *biomass gasification*. 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 since the 1980s. Later, a consortium of researchers and companies has formed to jointly develop biomass gasification in integrated P&P mills. The extensive R&D background enables the fact that suitable technology is near commercialization to respond to the current EU requirements.

The low price for oil kept many research results unutilized until recently, and the interest of the forest industry was low. Finland took up only recently the requirements of the EU Directive, and the globally lowering price for paper products and an increased price of fossil fuels have only just added the interest of P&P producers towards biorefineries. A Finnish pulp and paper producer UPM took the first move among the forest companies, stating that it will start the production of DME through gasification in connection to its pulp mills in Finland and in other European Countries. A Swedish-

Finnish producer Stora Enso has also announced a co-operative venture with Neste Oil to start the production biodiesel.

Box 1 here

For several reasons, but especially due to increasing outsourcing of manufacturing, the need to improve the 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 the electronics and integrated circuits have developed rapidly. The development of RFID has been mainly carried out in other sectors than the pulp and paper industry, and the development of RFID technology in the sector has arisen through combining technologies from different industrial sectors. 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 of extended producer responsibility (EPR) for electronics (2002/96/EC) and end-of-life vehicles (2000/53/EC), have created pressures to enhance the waste management and recycling in the industries targeting by the directives and, thus, created potential new markets for RFID based solutions.

EPR based systems for packaging and packaging waste have also created new markets for *recyclable and biodegradable moulded fibre packaging* that Hartmann has manufactured for decades. This development has taken place despite less ambitious goals set in Directive for recycling of plastic than fibre packaging. In addition, a tax on

packaging has favoured fibre packaging over plastic in some EU countries. Finally, increased oil price has also increased the price of plastic and, thus, supported the growth of moulded fibre packaging market.

4.2. Market changes influencing the development of environmental innovations in the Nordic pulp and paper industry

The results from the empirical case studies show that 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;
2) New markets created by EU-level (or national) environmental policies; and
3) Changes in other markets, such as in energy or electronics.

Changes in the existing markets for P&P products have taken place mostly due to intensified competition with the more southern countries with lower resource costs. In addition to major investments in production in southern countries, this development has made Nordic producer companies aware of the need to improve the cost-efficiency of production and economies of scale, to create new products for existing markets, and to create products for new markets and product values chains. Our cases are examples of the three types of improvements. BCTMP and recycled packaging cases have created new products in existing business areas, while the biorefinery and RFID cases have explored new product value chains. Most of these have also targeted improved cost-

efficiency of production. The development has been on an international level, but within the pulp and paper sector.

EU-level environmental policies and their national implementation have created new markets or improved the existing markets for bioenergy, RFID tags and inlays, and recyclable or recycled products. Requirements for the use of biofuels and CO2 trading have been important drivers for the use of production by-products for energy, while extended producer responsibility (EPR) based regulations on packaging and packaging waste have been a significant driver for recyclable and biodegradable moulded fibre packaging made from recycled paper. EPR on electronics and end-of-life vehicles is also expected to enhance the markets for RFID tags and inlays. The recent environmental policy created markets have mainly occurred on EU or wider international level. National effects, however, may be created through national implementation and specificities of the international requirements.

Changes in other markets, such as in energy or electronics, have affected the search for efficiency improvements and for new product markets. Especially the increasing oil prices have created new markets for bioenergy and fibre packaging, because these products could replace oil-based fuels and plastics used for packaging. The globalising supply and distribution chains in electronics and other sectors, by contrast, have created needs for new types of tracking solutions as well as packaging. These driving forces can mainly be described as international development in other sectors.

Table 2 summarises the market changes related to different types of environmental innovations in the pulp and paper sector. It presents both the empirical cases studied in this paper as well as previous cases reviewed from literature. The review of literature on environmental innovation in the pulp and paper sector from earlier decades indicates a similar conclusion as that of our case studies with the exception that previously the policy-created markets originated from the national-level policymaking instead of the EU level.

Table 2 here

In general, the conditions for market changes spurring innovations in the pulp and paper sector have occurred on three levels: sectoral, national and international. Due to the nature of the pulp and paper industry, changes in sectoral markets usually cross national boundaries and affect the whole industry across the world. Also policy-created markets, as noted above, have increasingly moved to the international level, reducing the importance of national-level changes. Global trends in other industrial sectors have also clear implications in most environmental innovation cases, because they influence the cross-sectoral business opportunities and threats caused by increasing costs of production.

5. Discussion

According to Chaminade and Edquist (2006) very little is known about the formation of new markets and they call for further discussion on the adequate division of labour between public and private actors. Our findings indicate that it is not only the

expectation of a *new* market that pushes inventions into innovations. In low and medium technology sectors dominated by incumbent firms, such as the pulp and paper industry, changes in the existing markets may be needed to push the companies to innovate harder in the first place. The tightening competition in the world paper markets have in effect woken up the paper producers to see that they may need alternative strategies and innovation in new product value chains to survive the future.

Obviously, there are significant differences between sectors and the more mature sectors tend to be less innovative and more resistant to change (Kemp et al. 2005). The view that innovation and technological change are associated only with high-tech industries such as electronics is also widespread (Schienstock and Hämäläinen 2001). Pulp and paper industry can be characterized as a mature, high-volume sector where the products are based on low technology but are produced with complex, integrated manufacturing systems utilising high tech. Thus, to support environmental innovation in this sector, significant changes in the institutional environment (such as environmental policies) are required.

To support environmental innovation, public policies are often important as identified by Chaminade and Edquist (2006) and others before them (e.g., Hemmelskamp 1997; Norberg-Bohm 1999; Kemp 2000; Weber and Hemmelskamp 2005; Kemp et al. 2005). Yet our cases also show that policies alone are in most cases not enough to make companies interested to invest in new technology, and supporting signals from other markets may be needed. Exceptions to this tend to be only those technologies, e.g., end-of-pipe solutions, that are directly required by policies (Hildén et al. 2002). The reasons

for the inefficiency of policies in promoting innovations on their own may relate to uncertainties in policy development, shifts in policy debates and the conflicting signals that different public policies often create on society (e.g., Norberg-Bohm 1999; Pollitt and Bouchaert 2000; Kivimaa and Mickwitz 2006). Short-term policy measures combined with long-term technical investments are unlikely to entice companies to make these investments. Thus, policies need to be foreseeable and continuous (e.g., Norberg-Bohm 1999; Taylor et al. 2005; Kemp et al. 2005) or supported by other market changes to generate innovative responses.

While earlier studies have shown that local or national environmental policies have been able to promote environmental innovations (e.g., Hyvättinen and Hildén 2004; Kivimaa and Mickwitz 2004; Taylor et al. 2005; Kemp et al. 2005), it appears that the internationalisation of both environmental policies and of markets will play an increasing role in future innovation processes. Internationalisation or globalisation has been argued to both ease and hinder environmental protection. On the one hand, international companies have a tendency to keep the same level of pollution control around the world or even export environmental regulation as a way to maintain competitive advantage compared less advantageously positioned and smaller players (cf. Garcia-Johnson 2000; Reinhardt 2000). On the other hand global competition has been claimed lead to falling commodity prices and, thus, increased resource use (Weizsäcker 2005). Our findings show that global market trends can strengthen the influence of environmental policies, but only when the trends happen to point towards increased sustainability, such as the increased oil price. Internationalisation of environmental policy, by contrast, may promote more environmental innovations,

because the markets they help to create are more extensive and thus more enticing to the innovating companies. The Nordic countries have been found to be important test markets for innovations (Schienstock and Hämäläinen 2001), but they are often too small to interest large investments from the pulp and paper producers.

It has also been argued that globalisation trends are accompanied by a diffusion of authority that limits the scope of manoeuvre of governmental actors (e.g., Petchow 2005). This may particularly involve environmental policies. It has been argued, for instance, that the focus of the EU Lisbon Strategy, which originally included an environmental dimension, has now been narrowed exclusively to boosting growth and jobs, and the European Commission has taken initiatives to cut down existing legislation and withdraw policy proposals – partly under the guise of "smart" or "better" regulation (Wilkinson et al. 2005). The question therefore raises on whether the environmental element can be maintained in innovation processes, if the opportunities for policy created markets for environmental innovation are removed through globalisation. However, examples from electronics sector show that EU-level environmental requirements for companies placing products on the market extend even beyond the borders of the EU (Kautto and Kärnä 2006). Thus, using companies as intermediaries of regulation and to control each other opens up possibilities for environmental product policies in a globalised setting.

Despite the internationalisation trends our results support also the 15 years ago made acknowledgement that national innovation systems still have an important role in supporting and directing processes of innovation and learning (Lundvall 1992). This has

not fundamentally changed at least in the context of the Nordic pulp and paper industry. Yet the dependence of innovation processes on international developments is also prevalent in our results. While the national systems play an important role in providing education and R&D infrastructure and maintaining national research networks, the innovation markets are increasingly international-level developments both in sectoral and policy-created markets. Thus, national innovation systems must increasingly take into account the international developments and, this may often limit the latitude of national policies. In effect, extended innovation systems may emerge in the EU-level.

6. Conclusions

The results of this study complement the literature on driving forces for environmental innovations, and deepen the insight into one of the functional elements of innovation systems – formation of markets. While the provision of knowledge systems, support for small firms and a combination of technical and institutional change are all important factors influencing innovation, the stage of commercialisation is not achieved without market influence. This market influence may need to be more extensive in the case of low-tech industries dominated by incumbents than in the case of dynamic high-tech sectors. Our examples from the Nordic pulp and paper industry show that environmental innovations in that sector were conditioned by important changes in three different types of markets (pulp and paper markets, policy-created markets and other sectoral markets), and that the policy-created markets needed support from other market changes. For environmental innovation, however, environmental policies can make or break the final

development. Thus a dependence exists both ways between general and policy-created market demand for environmental innovations.

Our results show also that national innovation systems are still very important in providing educational and R&D inputs for innovation and facilitating innovation networks, but innovation markets are increasingly dependent on international developments. Environmental policies act as important promoters of environmental innovations together with other market drivers. While previously local and national environmental policies have promoted innovations, policies are increasingly designed on the EU-level. Also many business sectors, such as the pulp and paper industry, operate increasingly on both international markets and international R&D networks. The EU-level Forest-Based Sector Technology Platform is an example of international R&D cooperation of the pulp and paper industry. In effect, due to Europeanisation of policies and of industrial cooperation, previously national innovation systems may actually extend to the EU-level.

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Table 1. Empirical cases of technological inventions/innovations (a more detailed description is found in Kivimaa et al. 2007).

Technology cases	Description	Environmental benefits	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 CO2 neutral way to produce electricity, increases the yield of electricity compared to available technologies	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 DME, a clean burning transport fuel, from a by-product of pulp making through a gasification technique	Reductions in CO2 emissions by replacing fossil fuel use in vehicles, has a higher efficiency than other options for producing transport biofuels	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. Röj, 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 CO2 emissions through replacing fossil fuel use in vehicles, has usually a higher efficiency than agriculture-based solutions for producing transport biofuels	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 CO2 emissions through replacing mineral oil	Interviews: P. Axegård, STFI, 31.10.2006 Newspapers: Nyteknik 7.6.2006
New production / products in the core business area			
BCTMP (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 half the amount of chemicals and less energy than the sulphate pulp process (exc. the heat & power generated from suphate pulping). Reduced wastewater load, an almost closed water cycle. Indirect energy-savings in transport due to reduced weight of products.	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	Interviews: T. S. Winther, Hartmann, 12.12.2006 Other data: www.hartman.dk
New product value chains			

RFID (many developers in the 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	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 shorther 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	Interviews: S. Strömberg, UPM Raflatac, 19.10.2006 Communications at http://www.upmraflatac.com/europe/eng

Table 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 (this study & Kautto et al. 2002)	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 (this study, Andersen 1999 & Kivimaa 2007)	1990s -	Increasing price of wood-fibre in Denmark	Extended producer responsibility for packaging, packaging taxes	Increased (oil and) plastic packaging prices
POM – paper machine wet-end (Kivimaa & Mickwitz 2004)	1990s -	Improved efficiency, expansion of production to China and other new countries	(water emission limits in Spain)	
Conox – effluent concentrate combustion (Kivimaa & Mickwitz 2004)	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 (Kivimaa & Mickwitz 2004)	1980s -	Improved thermomechanical efficiency	SO2 and NOx emission limits in Finland	Low electricity price and regulated markets (hindrance)
Activated sludge (Hildén et al. 2002)	1980s -		Water emissions regulation in Finland	
Filters for air emissions (Hildén et al. 2002)	1980s -		National limits for air pollution	

Box 1. Summarising the drivers and barriers of biorefinery innovations

The context for bioenergy related innovations has changed over time and one can identify both drivers and barriers on a general level that have affected the developments in bioenergy technologies applied in the P&P industry. The developments show that significant progress has required strong drivers that have helped to overcome the barriers.

Time period	**Direct drivers** (direct relevance on the emergence or commercialization of specific technologies)	**Indirect drivers** (contributing factors in the innovation process)	**Barriers**
1980s	○ Low efficiencies in utilising black liquor ○ Concern for industrial air emissions, expectation of new air pollution control policies	○ R&D cooperation; public R&D funding ○ The oil crises of the 1970s and the emphasis on wood fuels in energy production ○ Discussions on nuclear energy	○ Technological uncertainly regarding gasification
1990s	○ Diffusion of new combustion technologies following permit conditions based on new air emission standards	○ Opening up of Nordic electricity markets ○ Scientific and political debate on climate change	○ Technological uncertainly regarding gasification ○ Low oil price ○ Lack of investment interest from P&P companies
2000-	○ EU requirements for transport biofuels ○ High oil price ○ Need for business opportunities & cost-savings for the P&P sector	○ Increased concern for climate change ○ EU emissions trading scheme supporting renewable electricity ○ Opening up of EU energy markets ○ Intensified R&D	○ Other technological options for producing biofuels ○ Price support for existing/competing renewable energy sources ○ Availability of wood resources