Pathways for Increased Use and Refining of Biomass in Swedish Energy-intensive Industry
Changes in a socio-technical system

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Abstract

Events in recent decades have placed climate change at the top of the political agenda. The European Union has assumed a vanguard role in global climate negotiations, pushing for ambitious international commitments. Furthermore, Sweden is positioning itself as a leader within the EU when it comes to setting the agenda for climate change. In Sweden, energy-intensive industries are responsible for a large proportion of greenhouse gas emissions and their ability to switch to a renewable energy source could contribute significantly to the transition to a decarbonised economy.

This study analyses the role of three energy-intensive industries with regard to increased refining and use of biomass and will also take a glimpse into the future in an attempt to gain further insight into what will affect future developments in this area. The study is limited to the pulp and paper industry, the iron and steel industry and the oil refining industry as well as the EU legislation that affects these industries. For each industry the operations of the following case companies, Södra, SSAB and Preem AB, are analysed specifically and for each company one or two selected plants exemplify the outcome of the implementation of different technologies. This interdisciplinary study combines a range of methods taken from engineering and social sciences.

The industries studied all have different preconditions for transformations and the technological options available diverge to a large extent. There are many options for the pulp and paper industry compared to the iron and steel industry and the oil refining industry. The most likely technological option for this sector is to utilise internal resources for conversion to energy or material products and export of excess energy. Options for the steel producer SSAB include the substitution of part of the coke in the blast furnace with biomass or refined biomass products such as syngas and biomethane and forming an industrial symbiotic partnership. There are several options for the oil refining industry to substitute fossil feedstocks without the need to modify the existing infrastructure. One option is hydrotreatment of bio-oil into green diesel, which will be implemented at the Preem refinery in Gothenburg. However, green production of transportation fuels and substitution of coke in the blast furnace require large amounts of biomass and since biomass is a limited resource this is likely to act as a barrier to the development of these technologies.

Furthermore, it can be concluded that the companies studied could contribute significantly to the development of technologies that are in line with their core
capabilities, while the development of technological options that require a change in their core capabilities is more limited. This discovery is further supported by the finding that the EU directives relevant to this report do not push industrial operators beyond efficiency measures along established technological lines. On the one hand, these legislative instruments, which are designed in the spirit of ecological modernisation, encourage the most cost-effective technologies and processes for the abatement of greenhouse gases relevant to each industry. On the other, they do not appear to be sufficient to raise the cost of carbon emissions and this contributes to a situation where incentives to make different biomass-based technologies economic are not present on the market. Over a longer time perspective none of the case companies believes that biomass will have increased significantly in the Swedish energy system by 2050. These case companies claim that biomass is too limited a resource and can only contribute in part to the necessary substitution of fossil fuels.
Abbreviations

ADt – Air Dried Tonne
CEPI – Confederation of European Paper Industries
CCS – Carbon Capture and Storage
CHP – Combined Heat and Power
DRI – Direct Reduced Iron
DME – Dimethyl Ether
EU – European Union
EUROFER – European Confederation of Iron and Steel Industries
EUROPIA – European Petroleum Industry Association
ETS – Emission Trading Scheme
FT – Fischer-Tropsch (diesel)
FCC – Fluidised Catalytic Cracker
GHG – Greenhouse Gases
LPG – Liquefied Petroleum Gas
RME – Rapeseed Methyl Ester
SFIF – Swedish Forest Industries Federation
SNG – Synthetic Natural Gas
SPI – Swedish Petroleum Institute
Definitions

**Benchmarks:** Criteria based on the most efficient technologies and processes within a particular sector which give rise to safeguards by the EU ETS in the form of free allocation of permits if satisfied with an installation.

**Biodiesel:** Since biomass products are a new phenomenon in the fuel-producing sector no collective name for the renewable product has been adapted. In this report biodiesel is defined as diesel produced by esterification of bio-oils.

**Biofuel:** Transport fuel based on biomass feedstock.

**Biomass:** The biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste. (EU Directive 2001/77/EC, 2007)

**Biorefinery:** Integrated bio-based industries, using a variety of different technologies to produce chemicals, biofuels, food and feed ingredients, biomaterials (including fibres) and electricity from biomass raw materials. (Biorefinery Euroview Consortium, 2009)

**Carbon leakage:** A situation in which operations, jobs and, most importantly, emissions relocate outside the EU within industrial sectors exposed to global competition. The reason for this is the loss of competitiveness resulting from costs associated with the trade in emission permits.

**Core capabilities:** The set of knowledge that distinguishes and provides a competitive advantage to a company (Leonard - Barton, 1992).

**Demonstration plant versus pilot plant:** The demonstration plant is the link between the pilot plant and the commercial concept that is to be developed. In the demonstration plant, the technology’s commercial abilities will be proven whereas in the pilot plant the technology itself and the process will be validated. (Vattenfall, 2009)

**Diesel:** A petroleum fraction used as fuel in diesel engines (OED, 2009).

**Directive:** One of the primary legislative acts of the European Union (there are also Regulations and Decisions). Its obligations are directed at the result but not the
means of achieving that result, which means that Member States have considerable leeway regarding fulfilment of their obligation.

**Energy-intensive industry:** According to the energy tax directive from January 2007, energy-intensive industries have energy and carbon dioxide taxes amounting to more than 0.5% of the refining value. This part includes energy tax for the use of fuels and heat imported from an external producer but not energy tax associated with electricity use by industry. (Swedish Energy Agency, 2007)

**Green diesel:** In this report green diesel refers to diesel produced from biomass using modified conventional technologies at the refinery e.g. hydrotreating process units for the production of green diesel with tall oil as feedstock.

**Refining of biomass:** Converting biomass into higher value added products, such as chemicals, biofuels, food and feed ingredients, biomaterials, heat and electricity.

**Use of biomass:** Use of biomass, both in its natural, unrefined form and as refined products from biomass, is included. Biomass use is only considered to be carbon dioxide-neutral if planting takes place at the same rate that the biomass is harvested.
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1 Introduction

A major challenge is facing the European Union: to reconcile its aspiration to become the most competitive economy in the world in the short term with the growing challenge of addressing the environmental problem of global warming. The problem of climate change has arguably initiated a transition towards development along more sustainable lines where energy plays a central role. The European Union has assumed a vanguard role in global climate negotiations, pushing for ambitious international commitments and creating its own policies to mitigate global warming. Furthermore, Sweden is positioning itself as a leader in the EU when it comes to setting climate change agenda.

The process that is unfolding today can be best conceptualised in terms of an industrial transition – from fossil fuels to the use of climate-neutral energy sources. Particularly important in this development are existing energy-intensive industries and their interaction with climate change policies, technological development as well as strategies formulated by individual companies. This study is conducted in a Swedish context, focusing on Swedish industries affected by laws and policies that have their origin in Brussels. Recent decades have witnessed a process of significant Europeanisation of national legal systems, especially in relation to climate change regulation, a policy field where the EU is particularly keen to speed up in its Member States. The EU has conceptualised the challenge of global warming as an opportunity and is striving to design legislative instruments intended to influence industrial patterns of production and consumption in relation to energy without severely undermining the competitiveness of the regulated industries.

The focus of this report is on three industrial sectors in Sweden: pulp and paper, iron and steel and oil refining, all of which are energy-intensive and make up a large proportion of the value of Swedish exports. These industrial sectors account for more than 70% of the energy used in the Swedish industrial sector in 2007 (Swedish Energy Agency 2008a; Eurostat, 2004) and around 16% of the total Swedish fossil carbon dioxide emissions in 2006 (Swedish Energy Agency, 2008a; Chalmers Database, 2008). There are apparent differences among these industries in relation to the existing preconditions for turning towards increased use and refining of biomass. The pulp and paper sector is based on biomass feedstock and iron and steel and oil refining industries have traditionally used fossil energy sources. With these different prerequisites, the potential for implementing new technologies for use and refining of biomass are discussed and compared with the industries’ positions regarding implementation of these technologies.
Replacing fossil fuels with biomass-based feedstock or other renewable alternatives is one of several possible pathways for energy-intensive industries to meet climate change targets. However, technological options and stimulation policies are not always sufficient to make companies change existing structures in their industrial processes along the desired lines.

1.1 Aim

The aim of this study is to investigate the role of three energy-intensive industries with regard to increased refining and use of biomass. Many socio-technical parameters impact on the evolution of refining and use of biomass, and this study adopts three different perspectives in order to obtain a more comprehensive understanding of the unfolding processes. The three perspectives are technological, business and policy. One research question is formulated for each perspective:

**Technological perspective**: What are the possible technological options for implementing increased refining and use of biomass in the industrial sectors studied and what are the driving forces and barriers?

**Business perspective**: What are the views of the case companies on implementing technologies for increased refining and use of biomass and biomass use in the future?

**Policy perspective**: Are the European directives discussed in this report sufficient to stimulate profound changes in the industrial sectors studied and bring about industrial transformation in the form of a low carbon economy?

1.2 Systems perspective

This report studies the transformation of the *industrial energy system* into a more climate-neutral form. The point of departure is that energy systems can be conceptualised as socio-technical systems and therefore an interdisciplinary approach is applicable. The focus is on industrial transformation and restructuring, which is a part of a broader socio-technical transition.

In the context of this report, the analysis will be limited predominantly to the study of interactions between the strategies of pulp and paper, iron and steel and oil refining companies, with the EU directives addressed to them and an existing number of options in terms of innovative technologies for the refining and use of biomass. It is from the multi-level and socio-technical perspective that the report will strive to answer its main research questions. This interplay is illustrated from three system perspectives: policy perspective on the EU level, business perspective on the industry level and the technological perspective, see Figure 1.
Any technology for the refining and use of biomass that could be used in the industries studied are relevant artefacts in the system studied, as shown in Figure 1. Companies and organisations, such as universities, interest organisations, governmental bodies and non-governmental organisations, linked to the technologies, either directly or through networks, are considered to be actors in the system. The industrial sectors studied are exemplified by a case company; Södra for the pulp and paper industry, SSAB for the iron and steel industry and Preem for the refining industry. From the technological perspective, specific facilities are used to exemplify the potential to implement the technologies studied. The interest organisations representing each industrial sector, the Swedish Forest Industry Federation, Jernkontoret and the Swedish Petroleum Institute, are also part of the system. Institutions include regulations, norms and attitudes that define what the operators and artefacts can and should do. Legal instruments have been identified specifically as being highly important in steering the relevant industrial changes.
The industries in focus operate within the European Union and the laws and policies of the EU are thus highly relevant to their operation. National legal systems in relation to energy and climate change are embedded in the European Union context and are influenced to a large extent by the European energy decarbonisation objectives.

The EU affects the industries through directives and laws, both directly and indirectly. Legal instruments affect industrial strategies and sometimes choice of technologies. At the same time, policy needs to pass through a political decision process where businesses established on the market exercise their influence on the outcomes of this deliberation. Industries lobby and try to influence formulation of the directives, directly and through their interest organisations on the national and European level. Technological options offer business opportunities and/or possibilities for carbon dioxide emission reduction, cost reduction and increased energy efficiency. Internal factors in the form of, for example, excess heat, process operation conditions, investments, yields and product quality, play an important role in the choice of technology.

The temporal scope of the study covers a period from the present to 2050, the year by which the European Union has envisioned the achievement of its goal of a low-carbon economy and the year Sweden hopes to achieve the zero emission objective. 2020 is another important year due to the 20/20-targets set in the European Renewable Energy Directive, described in section 6.3. The Swedish government has committed itself to a more ambitious 50% target for 2020 under the Renewable Energy Directive (Government Offices of Sweden, 2008).

In the different industrial sectors, development, diffusion and use of a technology for the use and refining of biomass could make up its own industrial sublevel system, where different companies on the same sublevel interact with each other. However, the interaction focused on in this report is between companies in different industrial sectors rather than between companies within the same industrial sector. Interaction could be either in the form of co-evolution or competition, e.g. co-operation in research and the development of a new technology or competition for the same resource, see Figure 2.
In this report biomass feedstock is considered to be a limited resource and the use of biomass needed for the proposed technological options is therefore discussed and compared with the future biomass potential. The market for biomass feedstock is global and thus not limited to Sweden or the EU. The companies studied could therefore experience competition for biomass produced in Sweden from other Swedish operators as well as non-Swedish operators.

Adopting the interdisciplinary approach and combined perspectives used in this report offer several advantages. Since both social and technological aspects and their interrelationship are studied simultaneously, a deeper understanding of the system is achieved compared to separate studies of the individual parts. The illumination of technological options, business strategies and legal instruments reveals conflicting and co-operational interests and creates the potential for a profound understanding of sustainable future development in this area.

1.3 Motivations and delimitations of the study

The study is limited to three energy-intensive industrial sectors in Sweden: pulp and paper, iron and steel and oil refining. However, without denying the importance of national laws, the report focuses predominantly on the European legislative instruments as the majority of climate response policy measures originate in Brussels. In addition, for practical reasons only one representative from each of the following Swedish interest organisations, the Swedish Forest Industries
Federation for the pulp and paper industry, Jernkontoret for the iron and steel industry and the Swedish Petroleum Institute for the oil refineries, were interviewed for the part of the report concerning the policy perspective.

For each industry the business perspective analysis is further limited to the operations in Sweden of three case companies, Södra, SSAB and Preem. The case companies are chosen since they all have an ambitious attitude to climate change mitigation and have been shown to be interested in collaborating with universities in the development of innovative technologies. Due to the time constraint for this report the number of interviews at each case company was limited to two.

The technological options for refining of biomass were chosen by a thorough literature survey. Technologies in an early stage of development were not included in this study.

The technological perspective focuses on one or two facilities at each case company. Södra’s part of this perspective uses Södra Cell Värö and results from KAM 2, a model for a bleached kraft market pulp mill using the best available technology in Scandinavia. Södra Cell Värö is a net exporter of district heating and electricity and is assumed to be the first of Södra Cell’s three Swedish mills to become independent of fossil fuels. By supplementing results from Södra Cell Värö with results from the KAM 2 model it is possible to calculate biomass demand for different technological options, which would otherwise have been too time-consuming for this study. KAM 2 is a model developed as part of a project conducted by Mistra. It includes detailed data for energy and material streams in a kraft pulp mill. A lot of previous studies, e.g. (Pettersson, 2009), are based on KAM 2, which further increases the possibility of combining the results from this study with earlier results. The time perspective in this study is further justification for using KAM 2 as an example here, since it can be assumed to be a better model for a future pulp mill than analysing a specific facility.

For the technological perspective regarding SSAB, SSAB Strip Products in Luleå was chosen as a case facility. As regards this industrial sector the research centre MEFOS (for further information see www.mefos.se) could provide valuable data. SSAB Strip Products’ close link to research and convenience with regard to interviews, as MEFOS is also located in Luleå, were contributing factors in choosing SSAB Strip Products as a case facility. As regards Preem, both the company’s refineries were included in the technological perspective since the mode in which they operate has the nature of supplementation rather than two individual
and separate facilities. The refinery in Gothenburg is quite simple and small, while the Lysekil refinery is larger and more complex.

Due to the limited time available only brief calculations were possible regarding biomass demand, not including energy balances, economic calculations or CO₂ emissions.

Finally, the analysis from the technological perspective is limited to a comparison between biomass demand and the Swedish potential for increased supply of biomass 2020. However, biomass is a global, commercial material and the potential is thus not restricted to biomass in Sweden. The comparison in this study focuses only on the future potential of wood and agricultural biomass and municipal organic waste is not included in the potential.

### 1.4 The project in relation to previous studies

A lot of previous studies analyse the opportunities for efficient use of biomass in energy-intensive industries, e.g. studies by Lindfelt (2008), McKinsey (2008), Gode et al (2008), Andersson (2007) and Berntsson et al (2008) are worth mentioning in relation to this study.

Lindfelt (2008) analysed two strategies for decreasing anthropogenic carbon dioxide emissions: capturing and storing carbon dioxide and increasing the use of biomass. Lindfelt concluded that there is justification for biobased fuel production as it reduces oil dependence, but that biofuel production is often ineffective.

The consulting agency McKinsey (2008) has analysed the Swedish potential to reduce carbon dioxide emissions in order to reach the EU 2020 and 2030 target. The results are based on efficiency measures, replacement of fossil-based fuel and CCS. The results show a minimum carbon dioxide emission reduction in Sweden of 1.1 million per year for the pulp and paper industry, the iron and steel industry and the oil refining industry combined.

Gode et al (2008) reviewed the development status of technologies for the production of biobased fuel in Sweden. Results from the study show that biobased fuel production can often benefit from integration with CHP, resulting in increased overall efficiency. Policy instruments influence the development of biobased fuels and affect the incentives for polygeneration. Interviews show that the energy, forest and refinery sectors have ascertained business opportunities in polygeneration technologies.
Andersson (2007) analysed biorefining processes in a pulp mill with regard to energy efficiency, profitability and carbon dioxide emissions. The options evaluated are pellet production and hydrogen production from gasified black liquor integrated with a pulp mill. These processes were evaluated given different possible future energy market scenarios. Andersson concluded that it is important to adopt a system perspective to identify ways of using biomass efficiently.

Berntsson et al. (2008) conducted a pre-study commissioned by Preem related to effective production of future biofuels. The report is a summary of current research in different technological fields. The results show different opportunities for creating a more sustainable oil refinery and the need for interaction between measures as well as co-operation between researchers.

1.5 Synopsis

This report consists of ten chapters, including this introductory chapter. Chapter 2 presents the methods used in the study. Chapter 3 gives a theoretical framework for the analysis of the results.

Chapters 4, 5 and 6 introduce the reader to the main parties in the system studied, first in Chapter 4 by presenting the industrial sectors and their interest organisations, followed by a description of the case companies and the industrial plants representing each company. In Chapter 5 the technologies being studied are described and the potential for implementation in the different industrial sectors is discussed. Chapter 6 introduces and elaborates on the European directives relevant for this report.

The results of our study are presented and analysed in Chapter 7. The first part summarises our findings in accordance with technological, business and policy perspectives for each industrial sector: pulp and paper, iron and steel and oil refining. The findings according to the technological perspective are then summarised in section 7.4. The views of the case companies on biomass use in 2050 are presented in section 7.5. Finally, the findings according to the policy perspective are summarised in section 7.6.

The results are discussed in Chapter 8 and the final conclusions of the study are presented in Chapter 9. Chapter 10 outlines possible further work.
2 Methodology

This interdisciplinary study combines a number of methods from engineering and social sciences. Due to time limitations the study can be seen to rely mainly on a case study approach and data is collected from literature surveys, interviews and legal research. To achieve a deeper understanding of the literature survey, biomass demand for different technological options was calculated.

Figure 3 below illustrates how different methods are linked and how the results from the different methods are combined in the analysis of future development in the field of biomass refining and use in energy-intensive industries. The following sections then describe the different methods in more detail.

![Diagram illustrating how different methods are linked and how the results from the different methods are combined in the analysis.](image)

Figure 3 Illustration of how different methods are linked and how the results from the different methods are combined in the analysis.

### 2.1 Case study approach

The case study approach used in this study has been inspired by Yin (2003, p 13) who defines case study research as an empirical study that investigates a contemporary phenomenon within its real-life context, especially when the
boundaries between phenomenon and context are not clearly evident. A drawback using a case study approach could be that the results are simplified or exaggerated so that the conclusions are not generally valid (Merriam, 1998). On the other hand, a more quantitative method would not be applicable to our study since the number of industrial sectors, companies and facilities studied was limited, as a result of the time limitations to three months for the study.

The case study approach varies in scope for the different perspectives and different methods are used for data collection. The technological perspective includes one or two facilities for each case company, compared with what is possible from a strict technological point of view. Literature surveys are the main data collection method for this perspective, although on certain occasions the case company interviews contained information relevant to this part. The business perspective includes the three case companies and the data collected during interviews illustrates present and future visions in relation to refining and use of biomass at these companies. The policy perspective is restricted to interviews with Swedish interest organisations and legal research into EU directives. A further description of the different data collection methods follows.

2.1.1 Literature survey

Books, articles, reports, websites and policy documents were used as sources for the literature survey. A literature survey is always conducted to provide background information for the whole study. However, the main purpose in this study was to find information from which conclusions could be drawn about the possibility of refining and using biomass in the industries studied. Initial literature surveys were based on literature found at the respective authors departments’ library. Proceeding from that material, other relevant references were found. Library research sources, such as databases and scientific journals, were also used for the literature review. To find official documents, such as official surveys conducted by authorities, companies and agencies, and information about companies, relevant official websites were studied.

2.1.2 Legal research

Legal research is a method that is distinct from research in other disciplines (Pauwels et al. 1999) since it calls for an understanding of the hierarchical structure of legal resources. This method is employed both in the practical application of law and in academic legal research. It proceeds through several stages, identifying the relevance of primary and secondary law sources (sources that do not create legally enforceable rights) and even non-legal information in order to find an answer to the question(s) studied.
Regulatory pressures have been identified by scholars as being particularly decisive in industrial transformations (Eikland 2006; Andersen & Massa 2000; Huber 2000; Jänicke & Weidner 1995), and part of this report identifies and examines closely the legislative acts of the European Union in relation to the industries studied. The purpose is to understand the role of these directives in the European Union’s journey towards a low carbon economy. At the centre of the examination are directives aimed at mitigation of climate change and decarbonisation of energy sources. They were identified with the aid of the electronic sources of the European Union institutions. While it is probably possible to draw conclusions from the legal research and analysis of the legislative acts alone, an effort was made to find further empirical data for this research. The directives were therefore analysed in combination with literature studies on the shift to ecological modernisation in relation to environmental policy-making in the EU and data collected from the interviews with the representatives of the interest organisations.

2.1.3 Interviews

In this study qualitative, semi-structured interviews are used for interviews with case companies and the representatives of interest organisations. Kvale (1997) states that qualitative interviews focus on describing the nature or character of something, in contrast to a quantitative interview, which studies the quantity of something. A semi-structured interview means that the interview is flexible and is conducted as a conversation, guided by predetermined questions or topics. The interviewer is free to change the order of the questions and, when necessary, ask spontaneous questions so as to make the most of the relevant information and increase understanding of the matter studied (for more on this interview technique, see Rubin (2005). All the interviews were recorded on a dictaphone, transcribed in full and shared with the project group. For further details of the predetermined questions for each case company and interest organisation see Appendices 4 and 5. In each interview two interviewers were present to complement each other’s background and improve the quality of the interview; one with knowledge of business strategies or legislative instruments and the other with relevant technical expertise for each industry.

For each case company two representatives are interviewed, one at corporate group level and one at facility level. The selected representatives were involved in energy-related strategies and representatives at facility level also contributed with company- and facility-specific data. The results for these interviews are only considered to be valid for the specific company and no attempts are made to analyse this on an industry level. The interview results are also compared with
official statements for each company and the representatives interviewed are allowed to comment on the analysis of the interview results in order to illustrate the view of the company as well as individual company representatives. The interview references are given special attention in the reference list and are presented in a separate section. The reader should pay attention to the fact that almost all the references in sections 7.1.2, 7.2.1, 7.3.2 and 7.5 and some of the references in sections 7.1.1, 7.2.1 and 7.3.1 concern case company interviews.

As regards the interest organisations, one person in a key position in each association was interviewed and in total three interviews were conducted. The principal aim of the interviews was to question the representatives from the interest organisations in order to understand in which way the policies stimulate the transition to a low carbon economy within a particular industrial sector. The questions dealt with the impact of the legal instruments on the industries are viewed from their point of view. The interviews also aimed at gaining an insight into the planned strategic actions as a response to these impacts in the form of a) technological measures or investments; b) lobbying to influence policy formation or to prevent undesirable policy measures.

The views of the representatives from the interest organisations probably cannot be generalised into a common industrial position in Europe. It can, however, be argued that the planned strategies can still be regarded as being indicative of pan-European industrial sectors, that they belong to and share key characteristics in production, energy utilisation and their position on the global market, and they will therefore be sufficient to gain an insight into the degree of ambition in the legislative framework as far as the goal of a low carbon economy is concerned. Since these interest organisations are, in effect, political bodies, the reliability of the data collected depends to a large extent on the sincerity of the speakers. The data from the interviews is complemented with official statements from corresponding Brussels-based interest associations, the Confederation of European Paper Industries for the pulp and paper industry, the European Confederation of Iron and Steel Industries for the iron and steel producers and the European Petroleum Industry Association for the oil refineries. They are the main lobbyists since they have important points of access to the Commission, the central institution responsible for drafting EU directives.

2.1.4 Basis for calculations
To achieve a deeper understanding of the technological perspective, biomass demand for implementation of a technology in a case facility is calculated. The opportunities for implementation of a technology decrease if large quantities of
biomass are required. Higher biomass demand results in a longer transportation distance, which increases costs and carbon dioxide emissions. Transport by boat is an efficient alternative in terms of both cost and environmental impact. For a deeper understanding of the proportions of the biomass demands of the different technologies these are correlated to the increase in Swedish biomass supply for energy production in 2020. The Swedish potential for an increased supply of biomass from forest residues and arable land (including energy crops) is estimated at 30-56.5 TWh in 2020, see Appendix 6.

As mentioned in the definitions, use of excess process heat in a plant for refining biomass is considered to be an alternative for increased use of biomass. Further power production from biomass is in this study treated as refining of biomass. Economic aspects are not analysed in detail due to the time constraints on this study. Case facilities for each industry are presented in Section 2.1 and details of the calculations are presented in Appendix 1-3.
3 The framework of the analysis

The developments studied in this report can be best conceptualised as a transformation of an industrial energy system and a technological transition to the use of climate-neutral energy sources. As the report stated earlier, it will focus predominantly on three levels of analysis – policy, technological and business.

The framework of the analysis strives to understand the role of energy-intensive industries in technological transition by combining the concept of ecological modernisation with the companies’ capacity to change. Ecological modernisation serves as the main basis for analysis of the legal instruments and the industrial response to those instruments while the strategies adopted by the companies are studied by using as a point of departure different theoretical concepts that are being proposed by various scholars who have attempted to understand these developments. These two approaches are closely interrelated and complement the understanding of the phenomena being studied.

3.1 Ecological modernisation

The forthcoming analysis of the European directives relevant to this study is placed in the context of environmental policy and politics, which is conceptualised best in terms of ecological modernisation.

Ecological modernisation suggests that societies can continue the process of modernisation and at the same time address environmental needs without the need to undergo deep structural changes. In fact, continuing and furthering the process of modernisation and industrialisation is seen by advocates of ecological modernisation as the only possible way out of the ecological crisis. Moreover, due to the prevailing techno-optimism, businesses and industries are ascribed a major role in relation to sustainable development.

Ecological modernisation essentially presupposes a process of transformation towards industrial greening and a general shift to a more environmentally benign process of modernisation. This concept emerged for the first time in the 1980s and was presented by Huber (1985) and Jänicke (1992) as a largely optimistic vision for solving the environmental dilemma in developed countries (Mol and Sonnenfeld 2000; Mol 1999). Enthusiasm about technology and belief in current political institutions to manage environmental problems are its key features. Ecological modernisation, viewed as a prescription, has not always met with a positive reaction since its favourable interpretations of the role of economy and technology
were strikingly different from how some scholars viewed the solution to environmental problems. At the same time, ecological modernisation as a description of the character of the transformation of environment-related policies and politics from the mid-1980s onwards was received positively due its strong explanatory power to clarify how late modern societies deal with the ecological dilemma, i.e. by researchers such as Hajer (1995).

Ecological modernisation holds that recent decades have witnessed a gradual transformation in societal development from a trajectory of “simple” or “industrial modernisation” driven mostly by economy and technology (Bell 2008; Spaargaren et al. 2000; Bell et al. 2008: 165) to “ecological modernisation” (for more on this process, see Hajer 1995; Weale 1992) where environmental considerations are said to be playing an increasingly important role. The polluting and environmentally detrimental modes of industrial development are being reconsidered and replaced by environmentally friendly modes, successfully substituting financially inefficient end-of-pipe technologies with preventive technologies that are both innovative and competitive.

### 3.2 Companies’ capacity to change

Many authors offer a different understanding of changes at company level. The understandings presented in this section will be used in the analysis to understand the behaviour of the case companies. Ashford (2002) identifies three elements necessary for a more transformative technological change to occur. These are willingness to change, the opportunity to change, and the capacity to change. Of these three, it is the capacity to change which the author regards as the most crucial factor in any real industrial transformation. To Ashford it appears insufficient for industries to merely have a desire to change or to have the opportunity. They must be able to go beyond the modest efficiency measures and even displace themselves – this is the only condition if market-dominating industries are to bring about industrial transformation.

Other authors have tried to explain that there could be barriers to this displacement even if a firm strives to implement changes. Established companies often find it difficult to adapt to changes in their environment through implementation of a technological innovation if this innovation is not aligned with the company’s core capabilities. Leonard-Barton (1992, p 113) describes core capabilities as *the set of knowledge that distinguishes and provides a competitive advantage*. The author identifies four dimensions of this knowledge set, (i) employee knowledge and skills that are embedded in (ii) technical systems. The creation of knowledge and control
are guided by (iii) managerial systems. The final dimension comprises (iv) values and norms. The successful implementation of technological innovations depends on alignment with some of the dimensions of the core capabilities. The core capabilities are not easy to change, especially the dimension of values and norms, although changes in the company’s environment can make it necessary to change core capabilities in order to survive (Leonard-Barton, 1992). When a company tries to adapt to a changing environment the core capabilities can become core rigidities, e.g. as a high level of competence in one area can impede the development of technological innovation, which demands competence in another area.

An example of core capabilities becoming core rigidities can be found in a study of the disk drive industry (Christensson 1997). Even if established companies in this industry were aggressive, innovative and customer-sensitive in their attempts to sustain innovations of all kinds, they failed in their efforts to find new applications and markets for these new products. The established companies were in this case too sensitive to their customers, who only demanded improved performance of existing technological applications. The development and adoption of disruptive technologies was handled by new entrants to the industry (Christensson 1997). The core capabilities made the companies so good at what they were doing they were unable to see and develop new ideas.

Everybody forms mental models of almost everything, by making small-scale models to simplify reality (Foster and Kaplan 2001). In companies, mental models, especially managers’ mental models, can reduce the companies’ ability to react to changes in their environment. Managers develop a mental success model from actions taken based on stimuli from the environment and the result in terms of success and failure these actions have caused (Ansoff and McDonell, 1990). These mental success models are seldom explicit although they are still something a good manager uses as a mental filter to sort information and make decisions in their daily work (Ansoff and McDonell, 1990). However, a mental filter is only valid as long as the variables and circumstances it is based on are not changed. When the environment in which the company is acting is changing a new mental filter must be developed. As long as signals of change in the environment are handled according to an old mental filter the acceptance of new realities will be delayed, which could affect the information system, decision-making process, executive capabilities and control system (Foster and Kaplan 2001; Ansoff and McDonell, 1990).

Tripas and Gavetti (2000) provide an example of where mental filters impede evolution of core capabilities and radical technological change in an established
company. In this example Polaroid – originally a company in the instant image business – attempted to adjust to digital image technologies. Polaroid was characterised by a belief in the primacy of technology and that commercial success could only be achieved through major research projects (Tripas and Gavetti, 2000). Another belief within the company was the razor/blade model, which meant that the company could only make money from the consumables, not the hardware (Tripas and Gavetti, 2000). As the digital image technology evolved Polaroid were successful in developing digital image technology but stayed with their razor/blade business model and failed to develop manufacturing and product development capabilities, which prevented them from competing efficiently in this new market (Tripas and Gavetti, 2000).

Tushman et al (1997) claims that ambidextrous organisations, which have multiple organisational architectures to simultaneously foster both incremental and discontinuous innovations, are best suited to survive in a changing environment. The innovation stream in these organisations, focuses on patterns of fundamentally different innovations rather than isolated innovations. This is accomplished by having separate architectures working on incremental and discontinuous innovations (Tushman et al, 1997).

As a new technology and market evolve many companies generally participate in the competition although the number of companies reaches a peak when a dominant design emerges and thereafter declines rapidly (Utterback 1994). Being the first company to enter a market can generate first-mover advantages in the form of technological leadership, pre-emption assets and a lock in to the firm’s technology through buyer switch costs (Lieberman and Montgoemery, 1998). An example of a first-mover advantage would be if one of the industries studied in this report succeeded in implementing a technology for biomass refining in its processes and used profit from this process to buy contracts for biomass feedstock, preventing other industries from developing similar technologies due to lack of feedstock. On the other hand Olleros (1986) underlines the risk of pioneer burnout caused by pioneer externalities in the technology-creation and market-creation process, a high level of market uncertainty and a high level of technology uncertainty. Late-movers may benefit from free-ride possibilities on first-mover’s investments, resolution of technology and market uncertainty, gateways due to shifts in customers’ needs or technologies and incumbent inertia (Lieberman and Montgomery, 1998).
4 Energy-intensive industries in Sweden

This chapter introduces details of the three energy-intensive industrial sectors studied in this report. The industries’ interest organisations and research and development collaboration relevant to this study are also briefly introduced. First the pulp and paper industry, and in particular Södra and Södra Cell Värö, is presented. Thereafter the iron and steel industry, and in particular SSAB and SSAB Strip Products, is described. Finally the oil refining industry, and in particular Preem AB and Preem’s refineries in Lysekil and Gothenburg, is presented.

4.1 Pulp and paper industry

In Sweden the pulp and paper industry is one of the main industrial sectors and accounts for around half the energy use in the Swedish industrial sector (SEA, 2008). The industry employs around 23,000 people and contributes to 11% of Swedish exports (Swedish Paper Workers’ Union, 2009). There are around 50 pulp and paper production plants in Sweden, including 44 pulp mills (SFIF, 2009). Carbon dioxide emissions from this sector totalled 23 million tonnes in 2007 although only 7% originated from fossil fuels. Important pulp and paper companies in Sweden are Holmen, M-real, SCA, Stora Enso and Södra Cell.

The pulp mills can be divided according to the different processes employed for extracting the cellulose, which is either mainly chemical or mainly mechanical. Mechanical mills use much more electricity than a chemical pulp mill in their production processes. Mills that use the pulp for paper production on site are called integrated pulp and paper mills. The case company chosen, Södra, owns three Swedish chemical pulp mills, more specifically kraft pulp mills, and the focus here will thus be on this type of mill. The biomass raw material consists mainly of cellulose (about 50%), hemicellulose and lignin in a chemical pulp mill, see Figure 4, cellulose is separated in a digester in the presence of chemicals. The residual part is called black liquor, an intermediate product that is combusted in a recovery boiler as part of the regeneration of chemicals used in the pulp operation processes. High pressure steam is also produced in the recovery boiler.
The black liquor is converted into green liquor in the recovery boiler and then into white liquor in a process using lime. The lime needs to be regenerated in a lime kiln, shown in Figure 4. The black liquor contributes to the majority of the energy supply in a chemical pulp mill. Modern production plants for producing market kraft pulp, with high energy efficiency, are self-sufficient in terms of energy and are able to export energy products: electric power, district heating and bio-based energy sources such as bark, tall oil and lignin.

4.1.1 Swedish Forest Industry Federation

The Swedish Forest Industry Federation (SFIF) is both the trade and the employers’ organisation for the pulp, paper and wood processing industries. Its role is to foster the competitiveness of its members and represent their interests, mainly at national level but also at the EU level through their corresponding pan-European interest organisation, the Confederation of European Paper Industries (CEPI).

SFIF represents around 50 pulp and paper mills, approximately 150 sawmills, and a number of companies whose activities are related to the production of pulp, paper and sawn timber (SFIF 2009).
4.1.2 Södra
Södra has its origin in the Sydöstra Sveriges Skogsägareförening, which was founded in 1938. The association has grown and now has more than 50,000 forest owners in southern Sweden as members. The five business areas, Södra Skog, Södra Timber, Södra Cell, Gapro and Södra Windpower AB, have 3,600 employees. The business areas produce sawn and planed timber goods, interior products and paper pulp and in recent years the production of electricity from the mills has increased to such an extent that Södra is now a net exporter of electricity. Wood by-products are sold to heat and power stations, manufacturing plants, pellet factories and private homes. Södra has a market share of 20% of the bioenergy market in southern Sweden. (Södra, 2009)

Södra’s business vision is: “*To promote the profitability of its members’ forest operations by trading, developing and processing raw materials from forests, developing and marketing processed forest products, conducting an active industrial policy and providing felling services and other forest services*” (Södra, 2009). The financial crisis and economical downturn led to a fall in demand and declining prices during 2008 and as a result Södra’s profit declined. Net revenue fell from SEK 2,169 million in 2007 to SEK 513 million in 2008, mainly as a result of a weaker market for sawn timber (Södra Annual Report 2008). Another consequence of the economic downturn is that since the first of April 2009 both Södra’s pulp mills in Norway have been shut down to rectify the imbalance between supply and demand (Södra, 2009)

4.1.3 Södra Cell Värö
Södra Cell owns three pulp mills in Sweden and two in Norway. Södra Cell accounted for around 20% of the total kraft pulp production in Sweden in 2007 (SFIF 2009). Södra Cell’s Värö pulp mill is situated in western Sweden and has a production capacity of 400,000 tonnes of softwood kraft pulp per year. They also produce electricity and district heating, see Table 1. In 2007, Södra Cell Värö employed 350 people (Södra, 2009).
Table 1 Use of energy at the Södra pulp mill, Värö 2007 (SFIF, 2008)

<table>
<thead>
<tr>
<th>Energy</th>
<th>(TJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biobased fuel (incl. black liquor)</td>
<td>8,136</td>
</tr>
<tr>
<td>Fossil fuel</td>
<td>180</td>
</tr>
<tr>
<td>District heat exported</td>
<td>641</td>
</tr>
<tr>
<td>Electricity imported</td>
<td>73</td>
</tr>
<tr>
<td>Electricity produced</td>
<td>1,200</td>
</tr>
<tr>
<td>Electricity exported</td>
<td>210</td>
</tr>
</tbody>
</table>

The Värö pulp mill emitted 1 million tonnes of carbon dioxide in 2007 although only 3% originated from fossil fuels. An important goal for Värö is to have zero emissions of carbon dioxide from fossil fuels in 2010 (Södra, 2009).

4.2 Iron and steel industry

Most of the metallurgical processes of iron and steelmaking are energy-intensive and are conducted at temperatures above 1,000°C. Steel can be produced from scrap or from iron ore (integrated process). Steel production from scrap can be conducted in an electric arc furnace (EAF) and steel production from iron ore is often carried out in a blast furnace. Raw material in the form of iron ore pellets, coke and limestone are charged into the blast furnace. Iron ore is converted into iron by heating whereby the carbon atoms from coke and coal powder combine with the oxygen atoms in the ore. The liquid iron is then transported to a converter where the carbon content is reduced to below 2% and the iron becomes steel. This is accomplished by blowing oxygen under high pressure on the surface of the molten metal. The steel is then processed, e.g. with the addition of alloys, to satisfy demands regarding material properties in the end-product. (SSAB, 2005) Figure 5 shows a simplified process chart for an integrated steelmaking process with a coke oven and blast furnace.
Figure 5 A simplified process flow chart for a steelmaking process with a coke oven and blast furnace.

An alternative route for the production of iron from iron ore is a process called direct reduction. In this process the iron oxides are reduced to iron in solid form at lower temperatures. The product Direct Reduced Iron (DRI) is also called sponge iron. Here the reducing agent is a gas mixture comprising mainly hydrogen gas and carbon monoxide produced from natural gas or coal. DRI can replace scrap in scrap-based steelmaking. (Jernkontoret, 2000)

In Sweden the iron and steel industry accounts for 15% of the total industrial energy use (Swedish Energy Agency, 2008a). There are twelve plants in Sweden producing steel (Jernkontoret, 2008). Ten of these plants use scrap as feedstock and the other two (situated in Luleå and Oxelösund) produce iron-ore based steel at integrated plants with a coking plant, blast furnace and steel plant. The iron and steel industry’s primary energy sources are coal, coke and electricity. Coal and coke are used in the blast furnace as fuel and reducing agents and electricity is mainly used in melting processes in the scrap-based steel plants.

In 2007, carbon dioxide emissions from the iron and steel industry in Sweden totalled 6.4 million tonnes (Swedish Environmental Protection Agency, 2009).

4.2.1 Jernkontoret

Jernkontoret is the Swedish Steel Producers’ Association and was founded in 1749. Jernkontoret is owned by the Swedish steel works and one of its main functions is to act as a base for co-operation with the public administration. Jernkontoret
conducts technical research in co-operation with the steel producers in the Nordic countries. Jernkontoret also participates in research projects dealing with the European steel industry (Jernkontoret, 2008).

4.2.2 ULCOS

ULCOS stands for Ultra-Low Carbon dioxide Steelmaking and is conducted by a consortium of 48 European companies and organisations from 15 European countries. It is a co-operative research and development initiative that enables a drastic reduction to be achieved in carbon dioxide emissions from the best method available in modern steel production by at least 50%. The consortium consists of all the major EU steel companies, energy and engineering partners, research institutes and universities and is supported by the European Commission. (ULCOS, 2009)

ULCOS’ budget is EUR 59 million over a six-year period and the ULCOS partners contribute 56% of the total cost. The remaining 44% is financed by the European Commission. The ULCOS programme phase I (2004-2010) is investigating new technologies and includes a research phase and a pilot phase. Phase I will be completed in 2010 and after this, phase II (2010-2015) will explore some of the technologies investigated under ULCOS I with regard to their potential and feasibility under large-scale industrial production conditions. The results can then potentially be implemented at production plants some 15 to 20 years from now. (ULCOS, 2009)

Within the first part of the programme over 80 technologies were investigated and several promising breakthrough technologies that will facilitate carbon dioxide reduction in steel-making were identified. Four of these where selected and are being developed further within the ULCOS project (ULCOS, 2009):

- Top Gas Recycling Blast Furnace with Carbon Capture and Storage (CCS)
- ISARNA\(^1\) with CCS
- Advanced Direct Reduction with CCS
- Electrolysis

For the first three technologies the aim of 50% carbon dioxide emission reduction can only be achieved if they are combined with CCS (Carbon Capture and Storage). Electrolysis technology demands large amounts of electricity produced in a carbon dioxide-neutral way. Another option, mentioned by ULCOS, for reducing carbon dioxide emissions is the use of carbon from renewable biomass. (ULCOS, 2009)

\(^{1}\) Isarna is an old Celtic word for iron.
For EU integrated steel mills Top Gas Recycling Blast Furnace is considered to be the fastest deployment technology. In the Top Gas Recycling Blast Furnace the off-gases are separated and useful components (e.g. carbon monoxide) are recycled back to the blast furnace and used as reducing agents. This would reduce the amount of coke needed in the furnace. Oxygen is injected into the blast furnace instead of preheated air, whereby unwanted nitrogen is removed from the gas and CCS is facilitated. In phase II of the ULCOS programme there are plans to test this concept in a commercial-scale blast furnace. (ULCOS, 2009)

None of the above-mentioned technologies are correlated directly to biomass but in two of the processes, ISARNA and Advanced Direct Reduction, the natural gas can theoretically be substituted with biogas (biomethane) or syngas from biomass gasifiers.

4.2.3 SSAB

SSAB is a producer of high-strength steel. The company was founded in 1978 when the three largest steel producers in Sweden; NJA, Domnarvet and Gränges, merged as a result of the crises in the 1970s (SSAB, 2009a). The SSAB Group has three divisions for steel operations; SSAB Strip Products, SSAB Plate and SSAB North America, which were included through the acquisition of IPSCO in 2007 (SSAB, 2009a). Plannja and Tibnor are also part of the group and represent processing and trading activities respectively. The production facilities are in Sweden and the US, although in total SSAB employs 9,200 people in 45 countries. SSAB has been listed on the NASDAQ OMX Nordic Exchange, Stockholm, since 1989. Industrivärden is the largest shareholder with 21% of the votes. In 2008, the net revenue was SEK 6,998 million, a 29% improvement on 2007 (SSAB Annual Report 2008).

SSAB claims that its “vision is a stronger, lighter and more sustainable world” and SSAB has close co-operation with its customers in the development of new products and applications for SSAB’s steel. The high-strength steel could add environmental benefits to the products, which can “be lighter, stronger and last longer”. SSAB carries out much of its development together with its customers, other steel companies, the Swerea Institute\(^2\), MEFOS\(^3\), KIMAB\(^4\), Jernkontoret,\(^5\)

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\(^2\) The research institute Swerea provides research and consultancy services in manufacturing industry's key working areas.

\(^3\) MEFOS is a research organisation sponsored by the Scandinavian steel industry in Sweden.

\(^4\) KIMAB is an institute within corrosion and metals research.
Eurofer\textsuperscript{5}, the World Steel Association and different universities (SSAB Annual Report 2008). SSAB’s environmental and energy work is presented in a sustainability report (SSAB, 2008). In 2009, SSAB presented a summary of its environmental work in relation to the carbon dioxide emissions (SSAB, 2009b).

### 4.2.4 SSAB Strip Products

SSAB Strip Products is a member of the SSAB Group and has around 4,300 employees. SSAB Strip Products is the largest producer of sheet steel in Scandinavia and has a leading position in Europe in the development and manufacturing of high-strength steel grades. The company has operations in Luleå, Borlänge and Finspång. In Luleå there are a coking plant, blast furnace and steelworks. Slabs are shipped every day from Luleå to Borlänge where the company’s rolling mills and coating plants are located. The company also has a coil coating line in Finspång. (SSAB Strip Products, 2009)

SSAB Strip Products in Luleå had an annual (2007) production of 750 ktonnes of coke, 2,300 ktonnes of crude iron and 2,100 ktonnes of steel slabs. The consumption of some of the feedstock for the same period comprised 950 ktonnes of coal for coke production, 340 ktonnes of injection coal, 12 ktonnes of imported coke, 3,200 ktonnes of iron ore pellets and 390 ktonnes of scrap. Electricity consumption was 370 GWh/year. (SSAB Strip Products, 2008) For more detailed information about energy and fuel use see Table 2.

*Table 2 Energy and fuel used at SSAB Strip Products in Luleå 2007. Coke and coal are regarded as feedstocks. (SSAB Strip Products, 2008)*

<table>
<thead>
<tr>
<th>Energy</th>
<th>Amount (TJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>1,331</td>
</tr>
<tr>
<td>LPG</td>
<td>40.5</td>
</tr>
<tr>
<td>District heating (purchased\textsuperscript{6})</td>
<td>133.5</td>
</tr>
<tr>
<td>District heating (used)</td>
<td>91.8</td>
</tr>
<tr>
<td>Steam (purchased)</td>
<td>76.9</td>
</tr>
<tr>
<td>Steam (used)</td>
<td>38.5</td>
</tr>
<tr>
<td>Oil</td>
<td>23.2</td>
</tr>
<tr>
<td>Diesel</td>
<td>59.3</td>
</tr>
<tr>
<td>Petrol</td>
<td>3.1</td>
</tr>
</tbody>
</table>

In the processes at SSAB Strip Products in Luleå large volumes of energy-rich gas are formed (3,600 Mm\textsuperscript{3} gas in 2007). Of the ingoing energy, 93% is coal and 20% of the total energy demand is covered by recirculation of process gases (Grip &

\textsuperscript{5} European Confederation of Iron and Steel Industries

\textsuperscript{6} Some of the purchased steam and district heating is sold to Plannja, AGA and Nordkalk.
Larsson, 2008). These gases are reused for underfiring the coke batteries, preheating blast air for the furnaces, heating slabs etc. The plant is not equipped with a rolling mill\(^7\) at the site and excess gases are therefore delivered to a combined power and district-heating plant, LuleKraft AB. Here the gases are combusted as fuel for the production of district heating, electric power and process steam. Exhaust gases from LuleKraft are delivered to BioEnergi in Luleå and are used for drying sawdust which is then made into wooden fuel pellets. (SSAB Strip Products, 2005)

The steel contains chemical energy stored in the iron when converted from iron oxide to metallic iron and the scrap used in the process can therefore be reported as incoming energy. Approximately 37\% of the incoming energy is not recovered today and these process excess energy flows are of varying energy quality (Grip & Larsson, 2008):

- Cooling water with a low temperature. (11\%)
- Air-cooling of hot material, essentially hot slabs with a temperature of approximately 900°C. (6\%)
- Heat from hot slag. (3\%)
- Steam from cooling processes at the coke oven, converter, continuous casting etc. The temperature of the steam is approximately 100°C. (6\%)
- Hot flue gases, ~200°C. (3\%)
- Other energy flows not specified, including unidentified. (8\%)

In 2007, the carbon dioxide emissions from the plant in Luleå totalled 1.4 million tonnes. The specific emissions of carbon dioxide were below 1,600 kg/tonne crude iron (SSAB Strip Products, 2008)

### 4.3 Oil refining industry

The crude oil refining process is very complex and includes many conversion units in order to keep pace with market demand. The feedstock is crude oil, with a composition that depends largely on its original oil field. Approximately 7-15\% of the crude oil is used as fuel in the refinery (Szklo and Schaeffer 2007). The refinery process converts the crude oil using a number of different processes depending on which products are to be produced. Example of units are: desalting unit, crude distillation, vacuum distillation, hydrotreater, catalytic reformer, fluid catalytic

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\(^7\) At the rolling mill the steel slabs are heated to approximately 1,250 °C, in a slab furnace, before rolling. Energy-rich gases from coke ovens and blast furnace can be used for firing the rolling mill’s slab furnace. (SSAB, 2005)
cracker, hydrocracker and a number of residue-converting processes and gasoline-upgrading processes. The simplest refineries have no conversion units, only cracking units and the product is mainly heavy fuel oil. The more light products that are produced and the less heavy residues that are left the more conversion units are included in the process and the more complex the refinery. A simplified flow chart of an oil refinery can be seen in the figure below.

Today the trend is towards increasing the use of more sulphur-rich crude oil, increasing production of lighter products as well as stricter fuel specifications, including stricter sulphur regulations. The trend towards a larger proportion of lighter petroleum products implies growing energy usage but will also result in a product mix with a higher value (Worrell and Galitsky, 2005).

In Sweden, the oil refining sector accounts for 7% of the total industrial energy use in 2007 (Eurostat, 2004; Swedish Energy Agency, 2008a). There are five refineries in Sweden, two small refineries (Preemraff Gothenburg and Shell Gothenburg), two lubricant- and bitumen-producing refineries (Nynäshamn AB) and one large complex refinery (Preemraff Lysekil). In 2007, 2.7 million tonnes of carbon dioxide per year were emitted from the refineries in Sweden (Chalmers database, 2008).
4.3.1 Swedish Petroleum Institute

The Swedish Petroleum Institute (SPI) is a trade association for oil companies in Sweden with the aim of safeguarding and promoting the interests of the oil industry. The organisation was established in 1951. (SPI 2009a) It is predominantly active on the national scene and also co-operates with other European oil refinery interest organisations within the corresponding Brussels-based organisation EUROPIA (European Petroleum Industry Association) which represents the interests of the sector in dealings with European institutions.

4.3.2 Preem

Preem is the largest oil company in Sweden and the largest refiner in the Nordic region, with 30% of total refining capacity in the Nordic region and 80% in Sweden (Preem, 2009). Preem carries on trading in and refining of crude oil as well as sales of oil products, mainly in north-west Europe. Preem’s two wholly owned refineries are located in Gothenburg and Lysekil, with a total capacity of 17.4 million tonnes of crude oil per year (Preem, 2009). In Sweden, Preem supplies energy and fuel equivalent to 15% of the country’s total energy usage. The company was formed when Mohammed H. Al Amoudi bought OK Petroleum in 1994. Preem has 1,407 employees and net revenue of SEK 3,150 million in 2008 (Preem Annual Report 2008). Preem’s vision is to “lead development towards a sustainable society”.

Preem co-operates with universities, authorities and companies. Chalmers University of Technology works with Preem in the following areas; CCS, energy efficiency, excess heat, biorefineries, gasification, hydrotreating (Preem, 2009). Preem is part of a pilot project in Piteå where fourteen trucks will be driven on BioDME from black liquor (Preem, 2009). Preem is also co-operating together with Perstorp AB, which produces RME, which Preem then blends into its diesel fuel products (Preem, 2009). Preem and Södra, together with many other Swedish and Norwegian companies, are part of the Nordic Climate Cluster competence centre, which works with the development of renewable fuels (Karlberg, 2008).

Södra, Preem and Sveaskog also own around 60% of the company SunPine AB. The other 40% is owned by Kiram AB (Preem, 2009). SunPine AB is currently building a plant in Piteå for the production of raw material for diesel from tall oil (Preem, 2009). The raw material is then refined into diesel at Preem’s refinery in Gothenburg. The plant plans to start production in October 2009 and will be the first plant in the world to produce renewable diesel from a forest product on an industrial scale (Preem, 2009).
4.3.3 Preem’s refineries

Preem’s refinery in Lysekil is the largest refinery in Scandinavia and one of the most modern refineries in Europe, with both a hydrocracker and a catalytic cracker. The high complexity of the refinery makes it possible to process crude oil with a high sulphur content and to upgrade/convert heavy products to lighter products with a higher value. The refinery was built in 1975 and since then it has been revamped and refining capacity is now 11.4 million tonnes of feedstock per year. The district heating exports from the refinery in Lysekil totalled 121 TJ in 2007. The products are mainly gasoline, diesel, propane, propylene and heavy fuel oil. (Preem, 2009)

The refinery in Gothenburg, Preemraff Gothenburg, is a smaller refinery with a crude oil capacity of around 5 million tonnes per year. The products are LPG (butane and propane), motor spirits, aviation fuel, diesel, heating oil and heavy fuel oils. (Preem 2009)

The table below shows energy and fuel use for PREEM’s refineries.

Table 3 Energy and fuel used in Lysekil and Gothenburg. The table also shows steam production and heat delivery. The heating values from the fuel oil, the fuel gas and the coke are 41.6, 26.6 and 37.6 MJ/kg respectively (Preem, 2007a; Preem, 2007b).

<table>
<thead>
<tr>
<th>Energy and fuel</th>
<th>Lysekil [TJ]</th>
<th>Gothenburg [TJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imported electricity</td>
<td>1,739</td>
<td>500</td>
</tr>
<tr>
<td>Fuel oil consumption</td>
<td>530</td>
<td>619</td>
</tr>
<tr>
<td>Fuel gas consumption</td>
<td>19,014</td>
<td>6,406</td>
</tr>
<tr>
<td>Natural gas consumption</td>
<td>1,030</td>
<td></td>
</tr>
<tr>
<td>Propane consumption</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Coke from cracker</td>
<td>1,993</td>
<td></td>
</tr>
<tr>
<td>Steam production</td>
<td></td>
<td>1,462</td>
</tr>
<tr>
<td>District heating supply</td>
<td>121</td>
<td>1,514</td>
</tr>
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5 Biomass refining technologies

This chapter will provide the background to some of the existing biomass refining technologies that can be implemented in the industries studied for the increased use and refining of biomass. Several of the technologies studied are commercial although gasification and ethanol production from cellulose are still on the demonstration plant level. Technologies more specific for a certain industry are described in more detail in the result and analysis section.

There is a wide spectrum of technologies for refining biomass. A new technology often means several process steps, hence a technological system. Such a system can include pre-treatment of the feedstock, the main process and upgrading of the product. Implementation of a new technological system often means changes in the existing process, such as changes in energy balances and demand for feedstock. If a new technological system is integrated into the existing process system it is important to adopt a system perspective, which is exemplified in studies by Andersson (2007) and Hektor (2008). True for all biomass conversion technologies is the need for a long-term policy that ensures long-term supplies of biomass feedstock.

5.1 Gasification

Gasification of biomass is a partial oxidation of the biomass. The product is syngas, consisting primarily of carbon monoxide, hydrogen, carbon dioxide, methane and nitrogen. Gasification of biomass is a process that is more complex and less reliable than gasification of coal that has been commercial since the 19th century (Swedish Gas Centre, 2009). The biomass feedstock needs to be dried and ground before entering the gasifier. A key challenge for gasification of biomass is to improve the reliability and cost-efficiency of cleaning of raw gas to syngas.

Syngas can be used for the production of a spectrum of refined products such as methanol, synthetic natural gas (SNG), dimethyl ether (DME), FT-diesel and hydrogen. The syngas can also be used directly in a gas turbine for the efficient production of electric power. Different techniques for gasification result in different compositions of syngas, which makes it suitable for different end-products. The pressure and temperature in the reactor are important parameters, which can be varied to obtain the desired composition in the syngas. The gasification temperature is normally 500-1,400°C and the pressure can be up to 35 bars (Swedish Gas Centre, 2009). The overall conversion of biomass to syngas is an endothermic process.
The gasification process can be sorted into two groups, direct and indirect gasification, where the former uses heat supplied in the same reactor and the second uses heat from an external source, such as a boiler (Tunå, 2008). The main commercial techniques for gasification are fixed-bed, fluidised-bed and entrained-flow processes. Typically, the fluidised bed process is used for a fuel capacity of around 100 MW. The fixed bed process is suitable for small-scale applications, with a fuel capacity of up to 10 MW (Chopra et al., 2007). The entrained flow process is used for large-scale applications, with a fuel capacity of around 1000 MW, but for gasification of biomass a plant of this size would need an enormous amount of biomass import. A pilot plant with an entrained flow process is currently operating in Piteå, in northern Sweden, and is used for black liquor gasification (BLG) in connection with a pulp and paper mill producing kraft paper (Chemrec, 2009).

The advantages of gasification technology are:

- Flexible with regard to raw material and end-products, as well as in the size of the facility – offers many different applications and possibilities for integration in existing process plants.
- Transportation fuels that can be produced are compatible with existing engines (except for DME and hydrogen).
- The production process of SNG is suitable for CCS.

The disadvantages of gasification technology are:

- Applications with biomass as a raw material are complex and under development. The reliability of operation and cost-efficiency need to increase.
- The technology requires large investments.

### 5.2 Pyrolysis

Pyrolysis is a conversion process that produces a liquid oil and char. The oil can be used for electricity or heat production or can be processed further into transportation fuels or chemicals. This technology can therefore be interesting for a number of different industries. The pulp and paper industry, for example, can use pyrolysis technology to convert its by-products into bio-oil. The oil refining industry can use pyrolysis oil to produce green diesel through hydrotreating or cracking, see section 7.3.1. The iron and steel industry can use the pyrolysis products, both the oil and the char, as reducing agents in the blast furnace. Pyrolysis can also be of interest in connection with large gasification plants, since
converting biomass into a liquid could be an alternative to decreasing the transportation to gasification plants not located close to harbours (Berntsson, 2009). However, according to Bridgwater (2007) electricity production is currently the most promising opportunity for fast pyrolysis in Europe.

Fast pyrolysis is a process where biomass is heated rapidly to around 500°C in the absence of oxygen. To enable high liquid yields it is necessary to have high heating and transfer rates, a low reaction time and rapid cooling of the vapour. In this case the main product, bio-oil, can be obtain in yields of up to 75wt% on a dry basis (Bridgwater, 2007). Low heating and transfer rates and long reaction times are preferable for a high yield in char production. After cooling and condensing the vapour fraction in a liquid, bio-oil, is formed which can be used for the production of fuels or chemicals. The by-products, char and gas, can be used as fuel in the process. (Bridgwater et al., 1999)

Almost any form of biomass can be considered for fast pyrolysis although most of the work has been carried out on wood (Bridgwater, 2007).

The fast pyrolysis process includes drying of the feed to less than 10wt% water, grinding the feed into sufficiently small particles, pyrolysis reaction, separation of char, quenching and finally collection of the liquid product, the bio-oil. The pyrolysis process is endothermic and requires a significant heat input to raise the biomass to reaction temperature. However, the energy in the by-product charcoal is sufficient to drive the process (Bridgwater 2007). The figure below shows the pyrolysis process and different pathways for the products.
Today there are only a few pilot plants in the world that have been built and are operating. Large-scale pyrolysis has not yet achieved commercial status and the technology that has gained most acceptance for being reliable and capable of producing bio-oil in high yields is fluidised beds (Ringer et al. 2006).

The advantages of pyrolysis technology are:
- Produces a storable and transportable product, a liquid.
- The potential to produce a feedstock for the production of a variety of possible products i.e. from chemicals to electricity.

The disadvantages of the pyrolysis technology are:
- Large-scale characteristics are not yet proven.
- The lack of accepted specifications and standards for bio-oils.
- Users are unfamiliar with pyrolysis oil.
- Still relatively expensive.
- Because of polymerisation and condensation over time, bio-oils have limited storage and transportation time compared to oils based on fossil feedstock.
- No knowledge of issues concerning the environment, health and safety with regard to handling, transportation and use of pyrolysis oil.

Liquefaction is another technology which, like pyrolysis, converts solid biomass feedstock into a liquid. The difference is that liquefaction occurs under high pressure (1-240 bar), at a lower temperature (150 – 420°C) and in the presence of...
hydrogen and a catalyst (McKendry 2001). The bio-oil produced from liquefaction has a lower oxygen content, is less acidic and has a higher heating value compared to oils produced by pyrolysis (Klass 1998; Huber and Corma 2007). However, the technology has a higher reactor complexity, which makes it more expensive and the technology is not as developed as pyrolysis technology (Corma and Huber, 2007). This technology is not described in detail in this report but should not be excluded as a future alternative for biomass conversion, since despite a higher reactor cost, a better production yield could produce better revenue. Another technology that is at an earlier development stage is torrefaction, which is also a technology for converting biomass into liquids. This technology also has a higher production yield than pyrolysis (Berntsson, 2009) and in a more detailed survey of which technology to use for production of bio-oils, both liquefaction and torrefaction must be considered along with pyrolysis.

5.3 Transesterification

Transesterification is a process for converting vegetable oils into a more valuable product, biodiesel. This process is interesting for industries that have oil residues that can be converted into a biodiesel, such as raw tall oil in the pulp and paper industry, or industries interested in using biodiesel to blend into petroleum products, such as the oil refining industry. Biodiesel can be refined further through hydrotreating or cracking to produce green diesel, see section 7.3.1. Biodiesel can be produced from vegetable oils (triglycerides) such as peanut oil, palm oil, rapeseed, tallow etc. The plant oils usually contain free fatty acids, phospholipids, sterols, water, odorants and other impurities that make them unsuitable for use as fuel directly (Meher et al., 2006). Instead, the oils must be heated and mixed using a combination of alcohol (e.g. methanol) and a catalyst (e.g. sodium hydroxide) to become an ester, fatty methyl ester (FAME). Rapeseed methyl ester (RME), for example, is a biodiesel product produced from rapeseed oil. Currently, most biodiesel is produced from edible oils by using methanol and alkaline catalysts (Meher et al. 2006; Berntsson, et al. 2008).

The advantages of the transesterification technology are:

- High-energy liquids with less oxygen i.e. easier to convert into liquid transportation fuels.
- Biodiesel can be blended directly with petroleum diesel.
- Commercial process.

The disadvantages of the transesterification technology are:

- There is a limit of 10% blending with petroleum diesel.
According to the new Fuel Quality Directive, with an increasing obligation to reduce carbon dioxide, biodiesel produced from some vegetable oils might not reach the 6% reduction in lifecycle greenhouse gas emissions by 2020, see section 6.3.

Using vegetable oils could compete with food production.

### 5.4 Algal fermentation

A new technology under development that can produce biomass for biodiesel production is algal fermentation. This technology is still at the research stage but can be an alternative to vegetable oils and/or substitution for fossil oils. Use of algal oil can therefore be an alternative for industries interested in using bio-oils in their production. It could, for example, be an alternative for green diesel production in the oil refining industry. In this process algal biomass is produced through conversion of sunlight, water, carbon dioxide and inorganic nutrients. In the biomass recovery stage the algae biomass is separated from water and nutrients. The method most suitable for high value-added products and a large quantity of biomass is centrifugation (Grimaa et al., 2003). Unlike crops, microalgae grow very quickly and are exceedingly rich in oil (Chisti, 2008; Patil et al., 2008).

The advantages of algal fermentation are:

- According to Chisti (2008) the only renewable biodiesel that has the potential to replace liquid fuels derived from fossil oil completely.
- Using algal oil for biodiesel production does not compete with food issues.
- Microalgae do not require large land areas for growing. High oil content algae could produce almost 100 times more soya bean per unit of area of land (Patil et al., 2008).

The disadvantages of algal fermentation are:

- The economics of producing microalgal biodiesel need to improve substantially to make it competitive with petroleum diesel (Chisti, 2008).
- The production capacity depends on the geographical latitude where the facility is placed.
- Not on a commercial scale.
- The composition of many microalgal oils is unlikely to comply with the European biodiesel standard (Chisti, 2008)

### 5.5 Ethanol fermentation

Fermentation is a metabolic process whereby microorganisms convert biomass into energy under anaerobic conditions where organic compounds are both electron
acceptors and donors. Ethanol fermentation is used primarily by yeasts when oxygen is not present in sufficient quantity for normal cellular respiration. The yeast cell converts glucose into ethanol and carbon dioxide.

Fermentation processes can produce ethanol from any material that contains sugar. The raw material used in the manufacturing of ethanol via fermentation can be classified into three types: sugars, starches and cellulose materials. Sugars (from sugar cane, sugar beet, molasses and fruits) can be converted to ethanol directly. Starches (from corn, wheat, cassava, potatoes and root crops) need to be hydrolysed into fermentable sugars by the action of enzymes before fermentation. Cellulose (from wood, agricultural residues, waste sulphite liquor from pulp and paper mills) must likewise be converted into sugars by the action of mineral acids or enzymes. The enzymatic hydrolysis of biomass cellulose has yet to be developed although it was recently considered to be the most promising alternative as hydrolysis with acid incurs additional costs when substances toxic to the fermenting microorganisms are to be detoxified in the sugar hydrolysate. (Lin & Tanaka, 2006)

Today there are several commercial plants with ethanol fermentation from sugars and starches. However, ethanol fermentation from lignocellulose is not yet an established industrial process. Since 2004 a pilot plant for ethanol fermentation from sawdust has been in operation in Örnsköldsvik, Sweden. The next step is the opening of a development facility, with a capacity of 6,000 m³ of ethanol per year, in Örnsköldsvik in 2010-2011. (SEKAB, 2009)

A 2nd generation ethanol-fermenting plant has a demand for medium- and high-pressure steam and can therefore be integrated with, for example, a CHP plant or a plant producing excess process steam. Different kinds of cellulosic feedstock can be used and by-products from a pulp and paper mill are possible feedstock materials. The ethanol plant generates excess heat that can be used for district heating and the stillage that remains after the distillation can be used as a substrate in an anaerobic digester for biogas production. Alternatively, the stillage can be dried and residues from the evaporation can be used as fuel in, for example, a CHP plant. Lignin, separated from the stillage can be sold as fuel or as feedstock for chemical products. The technology, however, is not yet commercial and the investment costs are high and this is a barrier to implementation of the concept.

The advantages of 2nd generation ethanol fermentation are:

- Ethanol can be blended with gasoline and used in conventional engines.
- Demand for medium- and high-pressure steam and can be integrated with an industry producing excess process steam.
Generates excess heat that can be used for district heating.
Different kinds of cellulosic feedstock can be used e.g. by-products from a pulp mill.

The disadvantages of 2nd generation ethanol fermentation are:
- 2nd generation ethanol production is not a commercial technology.
- The investment costs are high.

5.6 Anaerobic digestion

Biogas is produced through the degradation of organic matter in the absence of oxygen (anaerobic digestion) whereby bacteria convert degradable organic matter into methane and carbon dioxide. This degradation, also referred to as methanisation, can be controlled artificially by fermenting pig and cattle manure, chicken dung, sewage sludge, industrial organic waste or agricultural crops. (Biogasmax, 2009)

A biogas facility treats the organic matter in a closed process. The organic waste is first homogenised and then in most cases, if the organic matter is of animal origin, pumped into a pasteurisation tank at 70°C for one hour or more to kill pathogenic microorganisms such as ehec and salmonella (legislation regulates which type of waste must be pasteurised). The pasteurised slurry enters a digester operating at a constant temperature of 36-38°C for mesophilic digestion or 50-55°C for thermophilic digestion. The methane concentration of the biogas produced is usually 60-70%. The biogas is recovered and can be used for generating heat and/or power. If the biogas is upgraded to a high level of methane concentration it can be used in cars as fuel or be injected into the natural gas grid. The digested slurry is sold to farmers as organic fertiliser. (Swedish Energy Agency, 2008b) Biogas facilities are currently operating commercially all over the world.

A biogas facility has a demand for low-grade heat and this demand can be satisfied with district heating or excess heat from industry. Any kind of organic matter can be used as a substrate in the digester, such as wastewater from a pulp and paper mill and stillage from an ethanol plant. Biogas can be used as fuel and as a substitute for some of the fossil fuels used in the industrial sector.

The advantages of anaerobic digestion into biogas are:
- All types of organic matter are possible substrates, e.g. domestic and industrial organic waste, and the technology thus does not compete with food production.
• The technology is commercial and a wide variety of anaerobic digesters are available.
• The technology is profitable in small-scale operation.

The disadvantages of anaerobic digestion are:
• The biogas produced needs to be pressurised before storage and transportation.
• If the biogas is used as a transportation fuel the vehicle engines constructed for liquid fuels need to be converted.

5.7 Production of pellets
Pellets are made from wood biomass with a spectrum of possible raw materials, by tradition mainly sawdust and chips but also bark, tree tops and stumps. The raw material is compressed into cylinder-shaped pellets for better combustion characteristics. Another advantage of pellets compared with uncompressed raw material is the volume density, which results in more cost-effective storage and distribution. The production process usually includes grinding into finer particles, drying of raw material, compression into pellets and finally sifting and cooling of the pellets. As a binding agent and to decrease friction in the compression process water, steam or lignin can be added. The increase in temperature in the compression process also facilitates binding of the pellets and increases their durability.

Drying of the raw material with a typical dry content of about 50% is the most energy-intensive part of pellet production. The raw material needs to have a dry content of about 90% (Andersson, 2007). The drying process demands 500-600 kWh/tonne pellets produced (Gode et. al, 2007). The potential to utilise excess process heat from an external source make this pathway for increased refining of biomass an interesting integration alternative for production plants with a large amount of excess process heat at low temperature. Another advantage of this technology is the potential for material exchange in the case of integration in a pulp and paper plant. At Södra Cell Mönsterås there is a pellet production plant linked to the kraft pulp mill plant and there is a sawmill on site. The pellet production plant uses excess process heat from the pulp mill and uses by-products from both the mill and the sawmill as raw material.

The advantages of pellet production are:
• Increases the heating value and thereby the economic value of raw material from forest sources with limited commercial applications.
• It is an established technology.
• It offers potential for energy and material integration with an external plant for higher overall efficiency.

One disadvantage of using tree tops and stumps as a raw material is that the pellets produced need to be combusted in plants with extended cleaning of the flue gases. Compared with traditional raw material (sawdust, chips and bark), tree tops and stumps have a higher chlorine and potassium content, which can be corrosive. This results in a limited market. (Nilsson et al, 2008)

5.8 Lignoboost

This process can only be implemented in a chemical pulp mill, since the raw material is black liquor, an intermediate product in the kraft pulp mill. Lignoboost is a process for lignin extraction from the black liquor, see Figure 8. Lignin can be used as a fuel, with an effective heating value of 25.4 MJ/kg dry solid and as a raw material for producing higher value added products such as phenols, carbon fibre, porous carbon and binders. To be cost-efficient, export of an energy by-product in the form of lignin from a pulp mill requires an increase in the overall energy efficiency of the mill. In the event of a production increase, which would require investment in a larger recovery boiler, Lignoboost can be an alternative to this investment and instead decrease the load on the recovery boiler (Axelsson, 2008), given that there is the potential to increase the overall energy efficiency.
Innventia (former STFI-Packforsk) started a demonstration plant for Lignoboost at the Bäckhammar pulp mill in 2007. In May 2008 the Innventia subsidiary Lignoboost AB was sold to Metso AB, which has continued the development of the process. The Bäckhammar plant produces around 4,000 tonnes of lignin per year, which is used mainly used for energy supply to the Fortum heat and power plant in Stockholm.

The advantages of the Lignoboost technology are:

- The process requires a lower investment cost compared to gasification of black liquor.
- It offers the scope to export excess energy in the form of lignin.

The disadvantages of the Lignoboost technology are:

- Installing this technology requires an increase in overall energy efficiency.
- The possible different end-products are still under development. At present the amounts of commercial products from lignin are limited.
- The total process for lignin separation has not been tested on a commercial scale although some of the production steps have been established on a commercial scale.
6 Legislative instruments

The policy perspective in this report aims to investigate European legal instruments under the climate and energy package directed at three energy-intensive and greenhouse gas (GHG) emitting industries in Sweden: pulp and paper, iron and steel and oil refineries with the purpose of gaining an understanding of the effect of these laws on the transformation of industrial processes in relation to energy in the selected industries.

The number of European competencies – policy areas which have a reference in the Treaties and where the European Union can legislate – has been growing continuously since the Union’s inception. In recent years in particular there has been an increase in regulatory pressure from Brussels in relation to environmental issues. The growing awareness of the urgency of the problem has prompted the European Union, a pioneer in international climate negotiations, to adopt an extensive legislative framework to address the challenge of global warming. Its main targets include energy-intensive industries. Their role will be explored against the backdrop of policy discourse on ecological modernisation, which replaced an earlier perception of environmental problems as a burden on the economy and instead conceptualises them as indications of inefficiencies and opportunities for businesses (Bell, 2008: 176). In essence, ecological modernisation suggests that an earlier unknown ecological rationality is being increasingly considered together with the previously dominant economic rationality and offers a promise that the goals of continued industrial growth and reduction in the negative impact on environment are not necessarily at odds.

European policies in relation to climate change are of direct relevance to industries in Sweden. The European Union has successfully created a unique system of regional co-operation where law has become a principle instrument of integration. The European Court of Justice in particular has played a vital role in this process by establishing, inter alia, the doctrine of supremacy of Community law, which requires Member States to integrate the Community’s legal norms into national legal systems and recognise the supremacy of European law over national legislative acts in the event of a conflict (for more on this, see Weiler, 1991).

In response to the challenges of global warming and an alarming growth in its dependence on foreign fossil energy sources, the EU has identified a trajectory of its future development as a low carbon economy which is planned to be achieved by the middle of this century. In particular, a route to a carbon-free society can be realised via decarbonisation, which is defined as an overall decrease in carbon
dioxide intensity from fuel that is generated or consumed (Kanoh, 1992; Sun, 2005). In other words, energy systems should reduce their reliance on fossil fuels and switch to less carbon-intensive energy sources.

This vision presupposes replacements, which require a major alteration in industrial practices in European energy-intensive and greenhouse gas-emitting industries and mark a new industrial revolution. During industrial transitions in the past a substituted energy source lost in the face of competition from the new source due to superior characteristics of the latter (i.e. energy density, compactness) e.g. industrial society made its transition from firewood to coal and then went over in the middle of the 19th century to the use of oil (for more details of this see Smil, 2003:195). The transition planned by the European Union involves decarbonisation, climate change and security of supply and is unlikely to take place in the absence of a strong and effective policy, the task of which is to push industries in the desired direction.

The analysis uses as a starting point the perspective that industries in general, and more specifically industries selected for the purpose of this analysis, will not initiate the process of industrial greening unless they are prompted to do so by relevant legislation. Laws, regulations and even established targets are considered to be the most important driving forces in bringing about change in an industry or a company. Huber, for instance, states that in as many as 74% of cases the changes made by companies were motivated by legal factors (Huber, 2000:277).

Due to the centrality of the legal framework for industrial change, laws that are designed to address the industrial patterns of energy were selected for analysis. Broadly, there are two general types of legal mechanism that are bound to influence the transformation processes in relation to the use of energy in industrial processes for the purpose of decarbonisation and climate change mitigation. On the one hand, there are laws that increase the costs associated with the use of fossil energy sources. On the other, different incentives are created that make the use of renewable energy sources more attractive in terms of reduced cost.

At the centre of the analysis in this report are legal instruments under the EU climate and energy package that arguably stimulate changes within industrial processes towards the target of decarbonisation and which are in the course to become law at the time of writing this paper. The effect of these legal instruments will be studied by examining the move by industry in a green direction, such as strategies to reduce greenhouse gas emissions or the switch to renewable energy sources. While the targets and goals of legislative enactments may appear to be
ambitious, their real role for potential technological transition needs to be investigated in the context of how they are received at the industrial level. Huber (2000), in an attempt to conceptualise the nature of ecological modernisation of businesses, proposes that industrial greening should be of a more transformative and qualitative character and go beyond the “business as usual” efficiency strategies of the producers. At the same time, Huber suggests that there is a great deal of evidence to confirm that the established companies' understanding of ecological modernisation is limited to the “efficiency revolution” (see also Andersen & Massa 2000).

While the word policy lacks a clear and uniform definition, it is normally understood as a programme encompassing an agenda in the form of desired goals and a set of means to achieve them and is adopted by state, international or supranational institutions. Legal and non-legal (i.e. financial aid programmes, dissemination of information) policy instruments can serve to achieve the ends of any policy programme. Laws or legal instruments are major aspects of any policy and they have a coercive character since they either compel or prohibit certain behaviour. Laws are often adopted with the ambition to change social reality (Alter et al., 2002) and are more concrete expressions of how to realise a particular vision, such as the EU’s aspiration to build a low-carbon energy infrastructure. Because of the binding character of laws, the study will explore the nature and the effect of the forthcoming EU directives aimed at pushing three energy-intensive industries studied in this report in a climate-friendly direction. A reservation needs to be made here that these directives will also be referred to as “legal instruments”, “legal measures”, “policy instruments”, “pieces of legislation” and “laws” interchangeably.

Industries have long been a focus of environmental concern for different reasons, from chemical pollution to ozone depletion and acid rain. However, their role has taken centre stage particularly in connection with the problem of global warming since it has been recognised to be mankind's grand challenge. The accumulation of greenhouse gases (GHG) in the atmosphere is linked to the very beginning of the industrial revolution, which was powered by the use of fossil fuels (Meadowcroft, 2002). Ecological modernisation suggests that rather than discontinuing the ongoing project of industrialisation, it can be “softened” and realigned along sustainable lines through the stimulation of a new technological revolution that will bring about low-carbon technologies and eventually result in the overall decarbonisation of the economy.
There are several reasons why this report investigates legislative instruments in combination with industrial strategies. To begin with, analysis of industrial strategies will complement and enhance insights into the effect of the legal instruments studied. In order to understand the capacity of the regulatory instruments they need to be analysed in the context of their interaction with the affected industries in question. Research into ecological modernisation often tends to concentrate on the study of either policies (Revell 2005; Hajer 1995; Jänicke and Weidner 1995; Jänicke 1992) or the behaviour of individual companies (Porter and van der Linde 1995). Studies surrounding the former usually describe transformation in the style and design of policy instruments; research in relation to the latter demonstrates the emergence of ecological rationality on the individual company level. However, a disproportionate focus on either of these areas of analysis fails to highlight the actual effects of the described changes. At the same time ecological modernisation presupposes the importance of both elements in this transformative process. Furthermore, from its inception, the focus of ecological modernisation has not been the path of economic development, which has always remained unquestioned, but rather a route of industrial development (Gouldson and Murthy 1996:14). As explained earlier, industrial strategies have a direct bearing on industrial transformation and the role of industrial operators is perceived to be central as carriers of this change. In relation to the problem of global warming they are important in the effort to move away from the resources that harm the climate most.

In addition to being legitimate players in the process of ecological modernisation as the ones that carry out the necessary changes, the role of industries is also growing as they become important shapers of the policies that are directed at them. There are probably very few researchers who do not support the idea that political space today is a multi-centric arena in which states are no longer the primary parties. This development has a particular bearing on environmental politics, where parties from different domains in society participate jointly in the formulation of strategies related to the preservation of the environment. This phenomenon is generally conceptualised as “governance” – a particular form of guidance of political and societal processes marked by the diffusion of power and collaboration between governmental and non-governmental parties. The transformation of the role of the government is accompanied by the move away from traditional top-down command and control policy instruments towards the employment of more flexible policy tools (Kollman 2007; Jänicke and Weidner 1995). Researchers point out that there is a relationship between this process and the gradually diminishing powers of the state (as a response to globalisation, which manifests itself through increased
pressure from business interests and the rise of international and supranational organisations) witnessed in the recent decades (Strange 1996; Schmidt 1995).

This form of public-private governance is especially true for the institutional settings of the European Union where stakeholders in particular policies are involved in the formulation of laws and policies that are designed to affect them (Wettestad 2008; Markussen and Svendsen 2005; Greenwood and Webster 2000, Michaelowa 1998). Following this logic, environmental decision-making is not only influenced by the interaction between the supranational decision-making bodies (the Council, the European Parliament and the Commission), but also non-governmental organisations and especially industrial interests. Along with state bodies and non-governmental organisations, businesses are thus legitimate political players in the EU arena, shaping the manner in which ecological problems are addressed.

6.1 Policy in the Spirit of Ecological Modernisation

The fact that laws and policies are formed in accordance with the principles of ecological modernisation – and demonstrate features of being flexible and market-based – does not necessarily mean that the policy in question actually brings about industrial greening. This forms the starting point for investigations. It has been argued by some critics of ecological modernisation (York and Rosa, 2003) that the theorists of ecological modernisation focus disproportionately on analysis factors that say more about the changes described rather than establish that these changes actually amount to profound improvements for the environment. For instance, a disproportionate focus on particular companies improving their environmental behaviour offers only anecdotal and unreliable evidence that these processes represent a general process that is being theorised. Additionally, demonstration that a change has taken place in the way policies are designed and formed also amounts to an unreliable claim that these policies lead to far-reaching structural changes at the industrial level.

The examination of the relevant EU directives will benefit from being placed in wider legal, political and social contexts. The analysis seeks to explain how these legislative instruments work in practice and the investigations therefore go beyond the analysis of legal texts. For that reason, before introducing the directives studied, an effort is made to elaborate on the details that have implications for forthcoming laws, such as the shift in the direction of ecological modernisation in general and more specifically at the European Union level, challenges that shape the EU energy policy as well as the existing competencies of the European Union.
The concept of ecological modernisation has been used by scholars in various disciplinary fields, elaborating on different aspects of this process. In relation to policy analysis, ecological modernisation has emerged as a discourse and a prominent strategy to address environmental problems by late industrialised societies. An overwhelming majority of researchers claim that a large proportion of environmental regulation in Western Europe is based on principles of ecological modernisation (Pepper, 1998; Baker et. al., 1997; Baker 2007; Gouldson and Murphy, 1996; Christoff, 1996; Hajer, 1995).

The emergence of this new “policy-oriented” (Hajer 1995: 25) discourse in environmental politics signified the break away from the ecology/economy dichotomy that was characteristic during the 1970s and early 1980s. The policy shift was in the first instance a result of the compromise between the demands of the radical environmental movements that questioned the industrialization project and the interests of those who wished for a continuation of the economic development along more or less similar lines (Hajer, 1995). Some scholars (Bell, 2008; Hajer, 1995) have conceptualised this shift as captivation and accommodation of a radical environmental discourse by the dominating structures in society. Given that existing economic, institutional, political and technological institutions undergo a process of transformation, ecological modernisation raises expectations that the growing ecological crises can be solved within the existing economic, social and political structures of society. The promise of continuous growth appeals to the strictest adherers of economic development. Further ecological modernisation was a reaction to the perceived inefficiency of the existing environmental policy instruments: the 1970s and 1980s saw an increase in environmental problems despite the existence of a strict regulatory framework.

Within this discourse, ecological problems are promoted increasingly as opportunities for businesses and signs of their inefficiency suggesting that businesses can offset the costs associated with environmental regulation through innovations (see the classic text from Porter & van der Linde 1995). Furthermore, industries are assumed to be capable of self-regulation and needing more flexibility; stringent environmental laws do more harm than good since industries should be given freedom to find their own innovative solutions for solving environmental challenges. The task of the policy is to address and stimulate the above developments.

Ecological modernisation recognises that businesses have a natural ability to strive to reduce their costs and argues that this characteristic can serve as a precondition for environmental improvements under the right conditions. The role of
governments in this process is reduced to discovering market failures – situations where the market fell short of setting a cost for environmental problems – and correcting them by relying on market solutions to make the cost associated with environmental damage visible. This is known as internalisation of environmental costs and is understood to be a principal approach capable of initiating the process of greening within businesses. Since the possibility to reduce costs is perceived to be a major source of business motivation to achieve environmental improvements, sustainability is translated into the language of businesses as economic efficiency. The effective policy that is aimed at improving environmental performance of industries is supposed to increase their costs in relation to activities that harm the environment. In the context of the industrial use of energy, for example, fixing a cost for carbon dioxide is believed to force companies to reduce the use of fossil energy sources, leading to a more effective use of these sources or employment of the more environmentally benign ones.

6.2 The shift towards ecological modernisation in the EU

The changes described above are also reflected on the supranational level: this section will provide details of a perceivable ideological shift that has occurred in the European Union in recent decades in relation to how environmental problems are addressed.

Environmental questions have slowly started to invade the political agenda of the Community since the beginning of 1970s. Their style was initially influenced by the Germanic legal tradition of the “watchdog state” and was permeated by the belief in strong bureaucracy capable of protecting the environment (Dezalay, 2007). The nature of these legal instruments was characterised by a “command and control” method (Kollman, 2007). This phase, which lasted for more than a decade, was gradually replaced by a new framing of environmental policy, which was marked by the general eco-modernist shift in the EU.

This transformation was accompanied by two major trends. In the first place, the European Union witnessed an alteration in its policy instruments. Growing dissatisfaction with the persistency of ecological problems has resulted in the common understanding that the current policy style was ineffective as it created an antagonistic relationship between the regulators and businesses. Therefore, the use of so-called “soft instruments”, or new policy instruments (NPIs) was encouraged. They were more flexible and were perceived to be a solution to a growing environmental crisis.
Another, more structural trend was accompanied by the change in environmental priorities of the European Union. While the earlier focus was on objectives of environmental policy, new goals became broader and were defined as *sustainable development* aims. This transformation was initiated first within the Maastricht Treaty and became more pronounced in the Treaty of Amsterdam, where the Union confirmed that sustainable development was one of its fundamental objectives. While the EU did not formulate its strategy of sustainable development until 2001 (Strategy for Sustainable Development, SSD, Gothenburg European Council), it has become acknowledged that the goals of sustainable development encouraged the Union to establish a synergy between environmental policy and other European policies. A new Article 6 (see TEU 1992) laid down a legal requirement for the institutions of the Union to pursue Environmental Policy Integration. In practical terms it meant that the Union in the early 1990s began integrating concerns for the environment with its concerns in other policy areas. This development is in line with ecological modernisation which recognises that environmental policy, if properly designed, can serve to promote further economic growth by encouraging efficiency, increasing innovation and creating new jobs.

However, integration of ecological concerns into other policies in the European Union has been far from problematic (Baker, 2007), especially in relation to managing conflicts of interest between environmental and economic considerations. This situation can be observed in relation to the integration of environmental concerns into energy and industrial policies; an argument that will be put forward here is that there is a tendency for an opposite process. Rather than an environmental policy’s agenda of climate change being a guiding principle in policy-making in energy or industrial questions, it sometimes becomes subordinated to the goals of the two latter policies.

The main driving force in this trend is the lack of the Union’s legal competence for regulating energy questions in the current Treaties. A reading of the current EU Treaties will confirm the absence of any Treaty mandate for the Union to legislate in this policy area. While the Community’s competence grew in accordance with the Monnet method, spiralling European integration from “lower” and more technical issues, such as creation of the internal market to those “higher in rank”, like environment and social policy, energy has tended to be the stumbling block for integration where Member States seemed to be unable to overcome differences in national interests and persistently refused to insert a chapter on energy during several recent revisions of the European Treaties. This situation has changed with the signing of the Lisbon Treaty, but its future is uncertain.
In the energy field, the EU faces two major challenges. One of them is global warming, and since this situation belongs to an environmental sphere, it is one of the policy areas which according to the Treaty of the European Union belongs to the EU’s competencies. At the same time there is another mounting challenge that concerns Europe’s security of supply. The amount of reserves of fossil energy sources is constantly diminishing within the EU, making its member states more dependent on energy from countries with less stable political systems. Also, when viewed against the backdrop of the rapid growth of energy-hungry economies such as China, India or Brazil, this trend sets alarm bells ringing in the minds of the European politicians (for more, see the Commission’s green paper “Towards the European strategy on the security of energy supply, CEC (2000)).

Nevertheless, despite the lack of legal competence in energy questions, the European energy policy is growing in response to the challenges mentioned earlier. This situation is an issue for concern when it comes to the creation of synergy between environmental and energy policies. The objectives of the European energy policy have until now been pursued through a number of non-energy provisions, such as environmental policy, internal market and competition policies. This means that some goals of the internal energy policy – security of supply for example – need to be met through the provisions of directives that pursue objectives of environmental protection. This explains why climate and energy package measures do not address climate problems exclusively; they also confront the Union’s growing dependence on fossil fuels while at the same time attempt to reconcile these goals with the objectives of the Lisbon process to become the most competitive global economy (see, for instance, a dual objective of increased security of supply and reduced greenhouse gas emissions for promotion of renewable energy sources in CEC, 2008 or CEC, 2006).

6.3 Presentation of the relevant directives

When it comes to climate change issues, the EU has assumed a vanguard role in international negotiations and is a forerunner when it comes to the design and application of policy measures in relation to mitigation of global warming. 2008 can be regarded as an impressive year for European Climate change policy. During the course of that year, several legal instruments under the Commission’s new climate and energy package were agreed upon, including the Renewable Energy Directive, which sets mandatory targets for transport biofuels and consumption targets for renewable energy sources in general. European leaders have also agreed on the revised rules relating to the European carbon trading scheme although exactly how several energy-intensive industries that are exposed to global trade will
be affected by the scheme was still to be decided at the end of 2009 (CEC, 2009b). Finally, the Fuel Quality Directive was amended, targeting *inter alia* oil refineries and setting binding targets to reduce their lifecycle greenhouse gas emissions.

All the directives selected for analysis here form part of the agreed EU climate and energy package. They are awaiting the formal ratification process, which will be some time this year, and they are therefore introduced here as a “proposal for a directive”. Their content, however, has been finalised.

In line with the spirit of ecological modernisation, the EU describes the process of addressing the challenges of climate change as an “opportunity” (CEC, 2008a) and a driver for innovation in European energy-intensive industries. To realise this goal, several policy instruments are designed with the aim of either increasing the cost of carbon or to facilitate market penetration for renewable energy sources.

### 6.3.1 Proposal for the EU ETS

The Emission Trading Scheme is Europe’s key instrument to combat climate change, fulfil its commitments under the Kyoto protocol and reduce emissions of greenhouse gases from power plants and sectors responsible for heavy greenhouse gas emissions. Power producers and energy-intensive industries are the main targets of this directive (Wettestad, 2008). It is the first and so far the only transnational legal regime for trade in carbon allowances, extending to all the EU Member States and it is of relevance to all industrial sectors discussed here. This instrument is in a state of transition, revised periodically to broaden and extend its scope in relation to targets and industries affected. It is also an instrument that can be described as “learning-by-doing” and is under constant construction. As in the case of all the other legal acts that are analysed here, its scope also reflects the fact that it is shaped by two opposing interests: those of the regulators (joint efforts of Community institutions to fulfil the binding obligations of the Kyoto protocol) and those formed by the common position of business interests (Wettestad, 2008; Markussen and Svendsen, 2005; Greenwood and Webster, 2000; Michaelowa, 1998).

In general, the regime that is created by this directive offers considerable choice to industrial operators in relation to how they plan to meet the identified environmental demands of the directive. A ceiling in the form of the fixed cap is set on total emissions for the European installations covered although a flexibility mechanism is built in on how to achieve it (CEC, 2009a). As it has been presented by the Commissioner DG Environment Stavros Dimas, businesses may choose “whether they reduce emissions or pay for reductions in other companies by buying
allowances” (Dimas, 2008). The Emission Trading Directive is based on the idea that the creation of markets for emission allowances will ensure that the reduction in emissions only takes place where it is most cost-effective to do so (Egenhofer et al., 2005:21). The total number of permits is limited and supply and demand are supposed to create the cost for producers in relation to carbon-intensive techniques and fuels, adjust the behaviour of industrial operators in the short term and promote investment in climate-friendly technologies in the long term (Ibd.).

There are generally two ways for allowances to be distributed: they are either allocated free of charge or auctioned. The scheme was launched in 2005 and the majority of installations received free emission allowances. This trial period run until 2008 until the second, “real” period of the EU ETS started. Even during that period (2008-2012) the majority of allowances were allocated and not auctioned.

A proposal for the EU ETS Directive concerns the third, more decisive trading period that will run for eight years, starting in 2013. It is awaiting its formal ratification and European institutions are elaborating on some additional details to this directive. The planned changes are expected to take effect in 2013. The goal of the third trading period is to achieve an overall, EU-wide 20% reduction in greenhouse gas emissions below the 1990s level in the absence of a global agreement on climate change (30% where the industrialised countries commit to comparable goals in ongoing climate negotiations), to decrease allocation and to gradually increase the auctioning of permits. The third phase will be characterised by full auctioning in the power sector and the inclusion of new industrial sectors and new types of GHG (oxide and perfluorocarbons) in the scheme (CEC 2009a).

6.3.2 Proposal for a Fuel Quality Directive

This is another piece of decarbonisation legislation which in this report is intended to impact on the oil refinery sector. It concerns transport fuels before they are consumed by automobile drivers i.e. before they are put into the vehicle, with the purpose of reducing what are known as well-to-tank emissions – all the carbon dioxide that is released during the exploration, extraction, production and distribution of a fuel. The notion of “lifecycle GHG emissions” is introduced and is to be applied to both fossil and renewable transport fuels. This directive specifically targets fuel suppliers to cut life-cycle greenhouse gas emission from road fuels by a total of 6% by 2020. The producers are supposed to begin reduction measures in 2011 with intermediate 2% and 4% targets for 2014 and 2017 respectively. However, the directive offers a choice as to how operators of oil refineries are to meet the directive’s objectives. This can be done either by cutting emissions when
processing the fuels or by blending lower carbon fuels into the fuels produced at oil refineries.

Another provision in the forthcoming directive that is relevant to oil refineries is the introduction of stricter rules for sulphur emissions. Reduction of sulphur content, however, requires more energy-intensive processes and this in turn is intended to have implications for the increase in the emission of carbon dioxide.

6.3.3 Proposal for a Directive on the promotion of the use of energy from renewable sources
Like the directives presented above, the proposed Directive on the promotion of the use of energy from renewable energy sources (the Renewable Energy Directive) is also a target-oriented piece of legislation. The directive mainly pursues two major aims – to increase the share of renewable energy sources to 20% and to boost the share of biofuel to 10% by 2020. These are legally binding and enforceable targets although Member States are free to choose how they achieve the required results. While 20% is an EU-wide target, it has been translated into individual targets for each Member State, calculated on the basis of per capita gross domestic product (CEC 2008).
7 Results and analysis

In this chapter results and analysis from all three perspectives are presented and examined. The first section describes the technological opportunities, business perspective and policy perspective for each industry separately. The results for technological options for each industry and for each case company are presented together with results from the interviews with representatives at Södra, SSAB and Preem. The last section contains a summary where the technological opportunities are presented together and evaluated; a summary where the future business perspective regarding biomass use is analysed. Finally, there is a summary of the results regarding the policy perspective.

7.1 Pulp and paper industry

The pulp and paper industry has extensive experience of handling and processing biomass from forest sources. Bio-based raw material offers many opportunities to increase refining of the intermediate and by-products. The existing infrastructure for the transportation of raw materials and storage possibilities on site can facilitate the increased import of biomass to the mills. Development in this sector is aimed primarily at optimising the financial value in the internal material streams. In the case of increased overall energy efficiency the mill needs the possibility to export excess energy in the form of energy products and many of the technologies mentioned in the following section offer new opportunities to meet this need. This industrial sector relies heavily on a supply of biomass at reasonable cost and is affected strongly by all biomass-related policies. In the following section the results from the three perspectives are presented for the pulp and paper industry and in particular Södra and Södra Cell Värö.

7.1.1 Technological perspective

Since biomass is the raw material for all Södra’s operations, all technologies for increased efficiency in existing processes as well as the adoption of new technologies, fall within the scope of this report. The oil crisis in the 1970s became the starting point for Södra’s work on improving its energy efficiency and as a result of its ambition to reduce dependence on oil and increase profitability, the internal use of biomass has increased. However, it is only recently that Södra could become a net exporter of energy, e.g. Södra Cell Värö has exported district heating since 2002 and electricity since 2007.

Examples of the effects of the implementation of technology for refining and increased use of biomass in this section are in most cases based on the reference
pulp mill, KAM 2, which is a model for a bleached kraft market pulp mill using the best available technology in Scandinavia, see Appendix 1.

**District heating originating from the use of biobased fuels**
Today, Södra sells 400 GWh district heating per year (Interview Andersson, 2009). Further investments and more efficient use of energy are planned to increase the capacity of district heating by 26 GWh/year at Södra Cell Värö. Even larger amounts could be produced at this and the other mills, although it is difficult to find customers for district heating, due to the geographical locations of the mills (Interview Karlsson, 2009b) and the monopoly of the district heating networks (Interview Andersson, 2009). Andersson (Interview, 2009) claims that Södra is willing to participate in building district heating mains but that the owners of the district heating networks are not interested in this heat since it would compete with heat produced from biomass at the owners' own power plants.

**Production of electricity and export of energy products in general**
The green certificates for electricity production have created an additional source of income for the pulp and paper mills. As mentioned, improved energy efficiency and investment in existing technologies have enabled Södra to become a net producer of electricity. Export of excess energy in the form of electricity is one way for Södra to increase the incentive to raise their overall energy efficiency further in the future.

Due to the different prerequisites at each mill, the three Södra mills in Sweden have different alternatives to increase the incentives for greater energy efficiency. Södra Cell Mönsterås has invested in a condensing turbine to increase electricity production, Södra Cell Mörrum is planning a LignoBoost process and Södra Cell Värö will install a bark drier during 2009 (Anderson, 2009). All these alternatives offer the possibility of increased export of energy products. As an example of the effects of these energy-related investments, Södra Cell Mönsterås increased its production of electricity from 554 GWh in 2006 to 622 GWh in 2007 (SFIF, 2009).

**Drying of bark and pellet production**
Södra is interested in finding additional energy carriers, except for district heating and electricity, which can transfer energy from the mill to external customers (Interview Karlsson, 2009b). Bark is one option – wet falling bark from the winter season or the additional import of biomass that can be stored and dried with excess heat during the summer and used for pellet production. These pellets are then sold to power plants for combustion. In this way excess heat is stored from one season to another (Interview Karlsson, 2009b). Södra is developing this technology and
investments have already been made in a bark drier for Södra Cell Värö. As an example, potential is estimated for the KAM2 pulp mill for pellet production using 0.11 TWh falling bark, which represents 0.05% of the energy content in imported biomass. This modest potential is a result of the already high overall energy efficiency of the KAM2 pulp mill.

**Gasification of biomass**
Södra Cell Värö has operated a low-temperature bark gasifier since 1987 and the gas is used to replace fossil oil as fuel in the lime kiln. Metso are running tests on purification of this gas, so that it can be used to produce biofuel, although Södra state that their main interest in this project is to increase the availability of the gasifier (Interview Karlsson, 2009b). Installation of the same kind of gasifier at Södra’s other mills would imply a capital cost that would be too high compared to technologies such as LignoBoost, which is planned at Södra Cell Mörrum, and the use of bark powder in the lime kiln, used at Södra Cell Mönsterås (Interview Andersson, 2009).

Södra is following the development of high-temperature biomass gasification and black liquor gasification, but can see barriers to these technologies (Interview Andersson, 2009). As regards high-temperature biomass gasification and production of Fischer-Tropsch diesel, the Fischer-Tropsch’s part of this process requires a scale of 600 MW_{biomass} in the gasifier to be cost effective. This makes the transportation of biomass too long and impossible for the pulp industry and gasifier to co-exist (Interview Andersson, 2009). One alternative could be to have a significantly smaller gasifier that produces SNG, where the minimum cost-effective size is 100 MW_{biomass} (Heyne, 2008). A major barrier to all technologies for the gasification of biomass is that the processes are still at the development stage, which results in a high financial risk and insecurity of operation.

An energy-integrated gasifier for the production of SNG in a pulp mill would produce 0.46 TWh SNG per year and require 0.83 TWh per year of additional solid biomass. This would represent a 10% increase in biomass demand imported to the mill, which is equivalent to 1-2% of the estimated increase in biomass supply in Sweden in 2020.

**Black liquor gasification**
In the case of a production increase or replacement of the recovery boiler in a kraft pulp mill, gasification of black liquor could be an interesting alternative. According to the discussion in the section about Lignoboost in Chapter 5, alternative use of black liquor decreases the load in the recovery boiler, which accordingly requires a
decrease in energy demand in the production processes. Commercial technologies for black liquor gasification can be divided into smelt-phase gasification and solid-phase gasification, although the latter is not of commercial interest at present. The smelt-phase gasifier is often a pressurised entrained bed flow reactor and the process temperature is around 950°C. Figure 9 shows a process flow chart when a facility for black liquor gasification is implemented at a kraft pulp mill.

Figure 9 Schematic process chart for black liquor gasification integrated at a kraft pulp mill (Pettersson, 2009, modified)

According to Andersson (Interview, 2009) there are barriers for Södra concerning black liquor gasification. Firstly, it is very expensive to install. Calculations from the EU 8RENEW projects show that the installation cost at Södra Cell Mörrum of a black liquor gasifier, including the additional bark boiler that is needed, would be at least twice the cost of a recovery boiler (Interview Andersson, 2009). Pettersson (2009) estimates the investment cost for a gasifier at SEK 5.5 billion and the investment cost for a recovery boiler at SEK 1.7 billion. From an environmental point of view, DME is often regarded as the optimal choice of product for gasification of biomass, but this would require an entirely new engine and infrastructure for distribution, which would result in much higher costs on the

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8 A pan-European project, supported through the European Commission’s 6th Framework Programme. For more information see http://www.renew-fuel.com
societal level (Interview Andersson, 2009). Secondly, only a pilot-scale process for the black liquor gasification technology has been demonstrated and Södra is of the opinion that efficiency in the gasification processes is low. Södra would therefore not be able to use its energy more efficiently using this technology and it would need to add more bark, probably more than what is available on the market (Interview Andersson, 2009). Thirdly the technology competes with LignoBoost for the same raw material, black liquor.

In the KAM2 pulp mill example all black liquor from the mill is used in the gasifier and the mill still requires 1 TWh additional bark per year plus 0.46 TWh more electricity per year. The additional demand for biomass represents an increase in the import of biomass of 13% to the mill and 2-3% of the increase in biomass supply in Sweden in 2020.

A pilot plant based on the smelt-phase gasification process with a capacity of black liquor syngas of 20 tonnes/day is in operation at the Smurfit Kappa pulp mill in Piteå, in the north of Sweden (Chemrech, 2009).

**LignoBoost**

Södra is implementing LignoBoost at its mill in Mörrum. Compared to black liquor gasification this technology is regarded as simple, reliable and with almost 100% efficient, and it creates the potential to store energy from one season to another in the form of lignin powder (Interview Karlsson, 2009b). Lignin can also be exported to other mills within Södra or external mills to be used as a fuel in the lime kiln. Other customers request lignin as a high-quality fuel or as raw material for higher-value products, e.g. chemicals.

According to Karlsson (Interview, 2009b) one reason for choosing this technology is that it creates the possibility of loading the recovery boiler less and creates the potential for increased production. With improved energy efficiency at the mill more lignin powder than is needed for the internal processes could be produced, which could be used as a desirable energy carrier in a form other than electricity or heat (Interview Karlsson, 2009b).

**Export of tall oil**

Tall oil is a by-product from the wood raw material. Today one company, Arizona Chemicals, buys all the tall oil available on the market in Sweden. When crude tall oil is processed at the Arizona Chemicals distillation plant one of the by-products is pitch fuel. The distillation plant produces 2 TWh of pitch fuel per year, of which the pulp and paper industry uses about one-third, mainly as fuel in their lime kilns.
Södra, Preem and Sveaskog are part of Sunpine AB, which is planning to produce diesel from tall oil. Production is planned to commence in Piteå in 2010 (Interview Andersson, 2009). Södra is interested in buying the diesel back from Preem and using it in their vehicles to reduce their carbon dioxide emissions. One of Södra’s targets is to be independent of fossil fuels and according to Andersson (Interview, 2009) the mill at Värö will be the first in the group to achieve this.

Pitch fuel produced from crude tall oil is used as a fuel at the Södra Cell Värö pulp mill in their lime kiln in combination with the gas from the gasifier on site. With a higher availability of the low-temperature gasifier more gas can be used in the lime kiln and as a result more pitch fuel will be available and can be used for diesel production (Interview Karlsson, 2009b). If Södra were to export all its tall oil, the other mills would also need to increase their replacement of fuel in their lime kilns. Södra Cell Mörrum is, as mentioned, planning a Lignoboost process where lignin is extracted and can be used as an alternative fuel in the lime kiln. At Södra Cell Mönsterås pulverised bark is used as an alternative fuel in the lime kiln. Calculations based on the production of market pulp at Södra in 2008 show a tall oil capacity of 0.68 TWh per year, representing 3% of the total energy content of the biomass imported to the mills at Södra, see Appendix 1.

**Anaerobic digestion for the production of biogas**
Södra has looked into several options for digestion to produce biogas. Sludge from Södra’s waste water plant is currently burned in the bark boilers or recovery boiler, but could be more useful in a digestion process, perhaps together with municipal sewage (Interview Andersson, 2009). The biogas could be used in vehicles at the mill or to replace oil in the lime kiln (Interview Andersson, 2009). The potential for this option is, however, limited; only 4 GWh of sludge per year is available.

**Export of methanol**
Södra has investigated whether the internally produced methanol could be purified and used as a fuel in their vehicles but so far the methanol is only burned for destruction (Interview Andersson, 2009). The potential for methanol as an energy product is limited; Södra Cell Värö has a capacity of about 14 GWh methanol per year. Methanol production at the KAM 2 mill represents 0.3% energy content in imported biomass. Södra has also studied several options for ethanol production integrated with their operations although the efficiency is too low to make any of the options financially viable (Interview Andersson, 2009) and according to Karlsson (Interview, 2009b) there is little possibility of increasing energy efficiency using this technology.
7.1.2 Business perspective

Södra’s energy strategy is to increase energy efficiency to minimise purchased energy so that only raw material is bought, become independent of fossil fuel and sell as much energy as possible (Interview Andersson, 2009). The company has an open attitude and seems to be interested in many different technologies that can contribute to greater energy efficiency, reduced fossil fuel dependence or conversion of internal excess energy to energy carriers that can be sold to external customers. Andersson (Interview 2009) explains that since 2003 the focus has been on investments that create the potential to sell energy. In 2006 and 2007, 50-60% of the investment at Södra was energy-related. In 2008, the figure was 80% (Interview Andersson, 2009). Profitability is the main parameter when deciding whether or not to invest in new technology. Another important parameter is that the technology is verified and has high availability (Interview Karlsson, 2009b).

Södra’s primary interest is to improve the pulp production process, although the company is also interested in using new technologies for producing non-cellulose-based products, e.g. district heating, electricity, lignin or tall oil, but only as long as these are produced from residues and thus do not compete with pulp production. Policies such as the green certificates for electricity could justify activities that improve energy efficiency and investment in new technologies although it is important that pulp production is not disturbed. The green certificates have stimulated investment in technologies for electricity generation and provided Södra with an additional source of income for its Swedish mills. This can be compared with the two Norwegian mills that have temporarily stopped production as a result of the recession. Södra’s focus on cellulose-based products rather than energy products even during times of weak pulp demand can be interpreted as such that Södra are relying on their core capabilities to achieve competitive advantages. All four dimensions of core capabilities contribute to this, but the fourth dimension, values and norms, seems to play a significant role, as the fibre from an emotional perspective, is regarded as too valuable to simply use as an energy source. The implications of the third dimension, managerial systems, or the Södra managers’ mental filter, are illustrated by the way Södra’s R&D efforts are directed at improvements in the cellulose products. The headquarters in Växjö focus at green chemicals and an R&D team of 50 persons based at Södra Cell Värö study mainly new materials and new products (Interview Andersson, 2009). The focus of the R&D efforts is thus not aligned with developments in the energy area which, as mentioned above, correspond to 80% of investment in 2008. One possible explanation for the lack of correlation between R&D and investments could be that development within the energy field is managed closer to operations. Karlsson
(Interview 2009b) explains that there is one energy controller at each facility at Södra and two energy controllers at the headquarters in Växjö although process engineers and managers at each facility also work on energy issues.

The pulp market, raw material prices and laws and policies are the uncertainties that are perceived to have the greatest impact on Södra (Interview Andersson, 2009; Interview Karlsson, 2009b). Whilst the use of pulp for newspapers is declining, demand for tissue, packaging and fine paper is increasing and Södra is optimising its processes to supply these markets (Interview Andersson, 2009). The price of biomass, chemicals and energy affect the pulp cost, although energy prices also affect Södra’s incomes and make it more difficult to decide how Södra optimises its operations (Interview Andersson, 2009). Green certificates have had a significant impact on energy-related investments and EU 20/20 targets, fossil fuel taxes and other policies will affect raw material costs and the profitability of investment in the energy sector. A result of the many legal instruments that aim at stimulating biomass substitution of fossil fuel is increased demand for biomass and rising biomass prices. Andersson (Interview 2009) illustrates this with the following example: To achieve the EU 20/20 targets, 3000 TWh of biofuel per year is needed. Using all the forests in Sweden would give 5,000 TWh and would thus only be able to satisfy this need for two years. At the same time, the price of biomass is increasing, even though all other raw material prices are falling as a result of the present financial crisis (Interview Andersson, 2009). If the ecological modernisation approach is behind the creation of these legal instruments, the approach has certainly succeeded in creating a demand for biomass-based energy carriers. Furthermore, it has stimulated Södra to invest in increasing electricity production and the export of tall oil although it has not motivated Södra to change its core capabilities and shift its main focus from pulp-based products to energy products in order to seize this new business opportunity.

7.1.3 Policy perspective

The pulp and paper industry is a wood-based sector and this very fact suggests that it relies heavily on the use of biomass. This is also the reason why carbon dioxide intensity in the industrial processes is not too high especially as opportunities for carbon savings exist via the re-use of its biomass residues.

As discussed earlier in the section on the technological perspective (see section 7.1.1), there are two main ways of making pulp for paper-making from virgin fibres, mechanical and chemical, and this fact affects the situation on how paper and pulp companies are affected by European legislation and the strategies they design in relation to it. The data obtained during the interview with the Swedish
Forest Industries Federation (SFIF) was complemented by the information acquired from the official statements of the Confederation of European Paper Industries (CEPI) in order to increase its reliability. CEPI is one of the main channels through which the SFIF carries out its lobbying activities in relation to the policy-making in the EU and the view of both organisations rarely diverges on matters relating to the European legal instruments being studied (Interview SFIF, 2009).

The EU ETS
The EU ETS affects the industry in two ways, directly in installations that still use fossil fuels in their processes and indirectly via higher electricity prices. The interest organisation CEPI on the European level goes further by claiming that the industry is even affected by higher prices for biomass since the ETS increases demand for their raw products (CEPI, 2008). As will follow from the discussion below, this issue is a constant source of concern for an industry that is based on the use of biomass as a raw material.

According to our respondent, the ETS, coupled with the growing price of fossil fuels (Swedish carbon dioxide tax) were important driving forces, steering pulp and paper firms away from the use of fossil fuels (Interview SFIF, 2009). The industry’s strength has been the fact that biomass is both a raw product and a by-product of its industrial processes and this makes the switch to the use of renewable energies much easier than in the case of many other industries. Not only are certain pulp and paper producers self-sufficient in energy, there is also an opportunity to become a clean energy supplier if residues are used efficiently. In Sweden, the system of green certificates has been particularly effective in inducing certain companies to invest in the production of renewable electricity. Furthermore, there is another factor that facilitates the transition to renewable energy sources. The main source of emissions is from the combustion of fossil fuels (CEPI, 2008), which is easier to tackle through fuel switches compared to process emissions in the iron and steel sector.

A similar opportunity does not exist in the case of mechanical wood pulp production. This process is very electricity-intensive. According to some researchers, there is generally a lot of potential for improving efficiency in relation to the use of electricity (Gielen and Tam, 2006). However, higher electricity prices as an indirect cost because of the ETS are not perceived by the industry as an incentive to improve its efficiency but instead as an unjust burden which should be resolved (Interview SFIF, 2009; CEPI, 2008). Industrial sectors that are exposed to global trade and competition cannot pass on the costs incurred in connection with the EU ETS to the price of their products. This situation can be compared with that
of the electricity generators, which were obliged to buy 100% of their permits from the beginning of the second trading period (which commenced in 2008) and could, by increasing the price, pass on the cost of buying permits to their consumers (alternatively, they could enjoy high revenues as a result of the high prices established by other operators of power plants if their installations did not need permits). This was possible as electricity is not an international commodity and its price is set locally.

The industrial sector has been particularly active on the national scene in Sweden in influencing governmental agencies to reduce the likelihood of an increase in the price of electricity by increasing the number of power providers and thus intensifying competition between them (Interview SFIF, 2009). It was especially important to make sure that the existing nuclear power plants continue operating and are not closed as was planned in accordance with an earlier referendum on the phasing out of nuclear power in Sweden (Interview SFIF, 2009). Furthermore, the industry’s interest in the existence of nuclear power plants is not only driven by concerns for higher electricity prices. The industry fears that the closure of nuclear power stations will create a situation in which biomass will be considered a raw material by electricity generators (Interview SFIF, 2009), especially in the context of the growing importance of climate change policies. In itself, this is not a new phenomenon in Sweden, where biomass has for a long time been regarded as an alternative to and a substitute for nuclear power (for more, see Anshelm, 2009).

**The Renewable Energy Directive**

The transposition of the Renewable Energy Directive into national legal systems is supposed to create financial incentives for various industrial parties to increase their use or production of renewable energy sources and especially biofuels. Since this legislation is in the form of a directive, it indicates that Member States may choose the most suitable way for their country to achieve the prescribed obligations in increasing the national share of renewable energy sources. For the pulp and paper industry the exact transposition of this directive is a matter of particular concern.

The industry fears that the likelihood of increased EU-wide competition for biomass is high as a result of the ambitious goals set for the increase in the share for the renewable energy sources (Interview SFIF, 2009; CEPI, 2008; CEPI, 2007). With the exception of biofuels, the choice of the energy mix to meet the renewable energy target is in the hands of nation states. The proposed directive may promote an increase in interest in the use of biomass, especially within the whole of the EU, where production of electricity is often based on carbon-intensive fossil fuels.
Biomass is an attractive resource, especially as its use is fully compatible with existing infrastructures, both in the electricity and transport sectors (in the form of biofuels). This energy source already accounts for two-thirds of all renewable energy sources in the EU (EEA, 2009). While this risk is relatively small in Sweden, especially as long as nuclear power plants are in use, the industry representative expressed concern regarding uncertainties in the transposition the Renewable Energy Directive by the government in Sweden (Interview SFIF, 2009). Furthermore, a situation throughout the whole of the EU suggests that incentives can be created for other industrial parties, in particular electricity generators, to substitute their fossil energy sources for biomass. This may eventually have consequences for pulp and paper producers in the form of higher costs for their raw material.

In connection with this it is necessary to mention that Ottosson and Anshelm (forthcoming) collected staggering evidence regarding SFIF’s attempts to maintain their monopoly on raw materials from forests. By manipulating data, the industry has gone as far as to persistently advocate that a figure representing the quantity of energy that can be extracted from the forest is about ten times less than what was suggested by government sources.

Some final words also need to be said. Overall, this sector, especially if it is based on chemical production methods, appears to have optimal preconditions for switching to the use of a renewable energy source – biomass. The SFIF has its own target for its member companies – to become independent of fossil fuels by 2030 (Interview SFIF, 2009). However, it must also be mentioned that even though this did not come up during the interview with the representative from the industrial sector, the industry still has competition concerns with regard to the impact of the EU ETS. At the time of writing this report the Commission was elaborating on the list of sectors which are exposed to global competition and risked a loss or reduction in their competitiveness due to extra costs associated with the emission trading scheme. Some of the installations that will satisfy benchmarking criteria (best available processes and technologies within the sector) will be allocated their allowances at no cost. It appears that the pulp and paper industry is also being considered to qualify for special exemptions although the exact details of whether this will occur or not and under what conditions will not be available until the end of 2010 (CEC, 2009b).

7.2 Iron and steel industry

The iron and steel industry emits large amounts of carbon dioxide into the atmosphere and the majority of this is of fossil origin. In order to decrease the load
generated by fossil carbon dioxide, the iron and steel industry is investigating more carbon dioxide-neutral ways of producing iron and steel. Within the ULCOS programme several options are being evaluated, see section on ULCOS in 4.2.2. The majority of these technologies however are not correlated to biomass. This part of the report analyses options for the increased use and refining of biomass in the iron and steel industry, particularly at SSAB and SSAB Strip Products. This issue is highlighted from three perspectives: technological, business and policy.

7.2.1 Technological perspective
Options for increased use and refining of biomass in the iron and steel industry are limited. One way is to replace fossil carbon with carbon from biomass, either as a reducing agent in the blast furnace or as a fuel in heating furnaces. Another possibility is to be part of an industrial symbiosis together with, for example, a biorefinery where excess heat from the iron and steel industry can be used in processes at the biorefinery.

Alternative reducing agents
There is research aimed at replacing coke with alternative reducing agents (Abdel Halim et al., 2009; Ogaki et al., 2001; Roubiček et al., 2007). Due to the physical properties it is not possible to replace all the coke in the blast furnace process as coke ensures correct gas permeability, the correct process temperature and correct process drainage (Interview Grip, 2008). There are several iron and steel companies replacing part of the coke in the blast furnace with the injection of, for example, pulverised coal\(^9\), fuel oil\(^10\), natural gas\(^11\) or plastics\(^12\) (Nozdrachev et al., 1998; Ogaki et al., 2001). However, none of the agents mentioned are renewable. If biomass is considered to be carbon dioxide-neutral the replacement of coke with methane, carbon monoxide, hydrogen, ethanol and methanol produced from biomass would decrease the carbon dioxide load from the ironmaking processes.

Advantages of replacing the coke with alternative reducing agents include (Chatterjee, 1995):
- Coke consumption can be reduced and the reduced demand for coke extends the coke oven life. The capital costs are lower compared to building or rebuilding coke oven batteries.
- Coke is expensive to produce and purchase.

\(^9\) SSAB Strip Products
\(^10\) Rautaruukki
\(^11\) Donetsk Metallurgical Plant
\(^12\) NKK Keihin Works
• Hydrogen present in alternative reducing agents decreases the amount of iron oxide reduced directly by carbon in the melting zone of the blast furnace. H\textsubscript{2} and CO reduce iron oxide by gaseous reduction in solid state resulting in decreased carbon consumption and heat requirements for direct reduction by carbon and consequently improved operation.

Injection of alternative fuels into the blast furnace is also associated with certain disadvantages (Chatterjee, 1995):
• Only the carbon content of the alternative fuel is a source of heat at the tuyeres and the dissociation of C-H, C-O and C-S bonds in alternative fuels consumes heat.
• The injected alternative fuel is often much cooler than the preheated coke and lowers the flame temperature in the blast furnace.

**Biomass injection into the blast furnace**
Utilisation of biomass as a reducing agent for ironmaking can mitigate carbon dioxide emissions. However, biomass usually has a low mass and energy density. The bulk density of rice husks, for example, is 100-125 kg/m\textsuperscript{3} compared to 800-900 kg/m\textsuperscript{3} for bituminous coals (De Jong, 2009). Additionally, the heating values of biomass are generally lower than those of coal due to higher molar concentration of oxygen in biomass. Typically, heating values for biomass are 10-18 MJ/kg compared with approximately 30 MJ/kg for black coal (De Jong, 2009). Consequently, the amount of biomass required to replace the coke is high. (Ueda & Ariyama)

A number of disadvantages are associated with the low mass density of biomass (De Jong, 2009):
• Relatively low heating value per unit volume
• Process control difficulties with regard to feeding (large volume injected per time unit)
• Require a large storage facility
• Expensive transportation

An alternative is carbonisation of biomass to enrich the carbon content and remove oxygen. The resulting biomass charcoal can then be injected into the blast furnace. Biomass is considered to be a limited resource and large amounts of biomass are needed to replace the coke and coal in the blast furnace.

During the interviews with representatives for SSAB and MEFOS options for alternative reducing agents were discussed. At SSAB Strip Products the coke is
replaced partly with pulverised coal, which is injected into the bottom of the blast furnace via coal injection tubes, tuyeres. Instead of this coal it is possible to inject other reducing agents, such as charcoal, tall oil and methane. According to Edberg (Interview, 2009) it is possible to replace approximately 30% of the carbon from coke with carbon from charcoal in the blast furnace process, but it is probably not possible to find this amount of pulverised charcoal on the market. Grip and Ryman (Interview, 2009) are in theory optimistic about replacing pulverised coal with charcoal but have experience from unsuccessful attempts to replace the pulverised coal and are sceptical about what amounts of biomass it is possible to find for this purpose. Not using biomass in the iron and steel industry would, however, create higher potential for biomass use in, for example, a CHP plant and might offer more efficient use of biomass from a wider energy perspective.

In 2007, SSAB Strip Products used 340,000 tonnes of pulverised coal for injection into the blast furnace, corresponding to 30% of the reducing agent. The rest is coke. Replacement with charcoal would require 1.36 million tonnes of dry wood or 7.5 TWh/year for charcoal production. For calculations and assumptions see Appendix 2.

**Biomethane injection into the blast furnace**

When injecting alternative reducing agents into the bottom of the blast furnace in order to replace part of the coke this may result in a lower flame temperature and could lead to increased coke consumption in order to maintain proper process temperatures and consequently larger carbon dioxide emissions (Interview Grip, 2009). Natural gas injected into the blast furnace is not a source of heat although its combustion products lower the temperature of the hearth gas. Abdel Halim et al. (2009) point out that natural gas also lowers the heat requirements of the charge in the lower heat exchange zone of the furnace by decreasing the degree of iron oxide reduced directly by carbon and coke savings can thus be obtained.

It is possible to replace approximately one-third of the weight of the injection coal with natural gas (methane) without adding more coke (Interview Edberg, 2009). This accounts for approximately 113,000 tonnes of methane. Producing this amount of methane, in a mesophilic biogas facility demands digestion of 1.5 million tonnes of organic MSW/year or 1.15 million tonnes of garden waste/year. Another alternative is to use SNG as a source of methane. If SNG from a biomass gasification plant is used it would require 0.53 million tonnes of dry wood or 2.93 TWh of biomass per year. For calculations and assumptions see Appendix 2.

**Gasification in molten iron-bath reactors**
There are gasification processes under development that use molten iron-based baths as a reaction medium, providing almost instantaneous heat transfer. Examples of this kind of process are the HydroMax® and the HyMelt® processes. The hydrocarbons (coal, petroleum, coke, biomass, shale oil etc.), steam and oxygen are injected into the gasification vessel containing a molten iron bath at a temperature of approximately 1,500°C. The process can be divided into two stages. In the first stage steam reacts with pure iron to produce iron oxide and hydrogen and in the second stage the iron oxide formed reacts with carbon to produce iron and carbon monoxide. (Diversified Energy, 2009; EnviRes, 2007)

According to EnviRes LLC (2007) and Diversified Energy (2009) the molten bath gasification technology is anticipated to lower the costs for syngas and the products that can be produced from it and it has also the potential to make gasification plants profitable on a much smaller scale. This can accelerate the market penetration.

The molten iron bath gasification process could have potential at an iron and steel plant where molten iron is available. Gasification of biomass offers an option for refining biomass at the iron and steel plant. Valuable knowledge of molten-metal industries, such as the iron and steel industry, can be used in the development of this new gasification technology.

Large-scale testing of the HyMelt® process has been conducted at MEFOS, a research organisation sponsored by the Scandinavian steel industry in Sweden, in 2003. The next step is a small commercial reactor that is planned to be built in Ashland, Kentucky. (EnviRes, 2007)

**Industrial symbiosis**

Several industrial symbioses can be proposed where excess energy from the iron and steel industry is used in biorefinery processes. Ueda and Ariyama suggest a biomass refinery where the biomass can be used more effectively. Raw biomass and lignin are dried and carbonised and decomposed into char, tar and gas. The char is used as a reducing agent for injection into the blast furnace. The gas and tar are used to generate heat for drying and carbonising processes and the tar can also be used as a binder in briquetting. Excess heat from the steelmaking plant can also be used in drying and carbonising processes.

Today several process energy flows are unexploited at SSAB Strip Products, see SSAB Strip Products in the Background section, and theoretically it would be possible to utilise some of this heat to cover a biogas facility’s heat demand. Most of the biogas facilities today are mesophilic (35-40°C) or thermophilic (55-60°C)
and the biogas plant thus has the potential to participate in an energy combine, using low-grade excess heat from, for example, an iron and steel plant. Biogas can be fired as fuel in heating furnaces, upgraded and replace part of the pulverised coal in the blast furnace as a reducing agent or be sold as transportation fuel.

Another theoretical option could be to use steam, produced at the CHP plant LuleKraft AB, in an ethanol plant. This increases the CHP plant’s underlying heat load and is most favourable in the summertime when the demand for district heating is low. Integration with an ethanol plant may cause a need to invest in an additional boiler in order to supply adequate heat for district heating in wintertime. This boiler can be fired with biomass. Alternatively, low-grade excess heat from SSAB Strip products can be used to produce district heating. The development of the district heating network in Luleå is limited by municipal borders and neither Boden nor Piteå have shown any interest in this (Interview Edberg, 2009).

There is also an option for collaboration between SSAB Strip Products and pulp and paper industries located in SSAB Strip Products’ surroundings, where black liquor from the pulp mill can be converted into syngas in gasifiers and the syngas can be used as a reducing agent in the blast furnace or a DRI plant.

MIDREX® (2009) has proposed an industrial symbiosis consisting of an oxygen plant, gasification plant, DRI plant (MIDREX plant\textsuperscript{13}), electric power plant and a steel mini-mill\textsuperscript{14}, see Figure 10. The gasification plant would be dimensioned to produce enough syngas for both the DRI plant and the power plant and the power plant would be dimensioned to generate all the electric power required for the air separation unit, DRI plant and the steel mini-mill. This concept provides opportunities for capturing of high-purity carbon dioxide for sequestering (CCS). This kind of solution could be a complement to the blast furnace process at SSAB Strip Products. The DRI produced can be charged into the blast furnace or into the converter. Some of the coke oven gas from the existing coke ovens can be used together with syngas in the DRI process.

\textsuperscript{13} Production of 1.6 million tonnes of DRI per year in a MIDREX plant requires 1.1 billion Nm\textsuperscript{3} of synthesis gas (containing <5\% non-reducing gases) (Cheeley, 1999).

\textsuperscript{14} A mini-mill is a type of steel plant that developed after 1970. A steel mini-mill uses scrap and DRI as raw material, rather than iron ore, for steel production. The scrap/DRI is melted in an electric arc furnace. (http://www.britannica.com)
In the case of an industrial symbiosis the physical distance between the plants is important as the heat losses and distribution network costs increase with distance. It is not realistic to move the SSAB Strip Products facility in Luleå and therefore options for collaboration with a biorefinery require an existing biorefinery within reach of the iron mill or the establishment of a new biorefinery in the iron mill’s immediate area. A barrier to industrial symbiosis is that the industry relies on another industry for energy and/or feedstock. The symbiosis thus requires secure, long-term co-operation. If the symbiosis means import of a feedstock from the biorefinery to the iron and steel plant, technologies that are not commercial are more insecure alternatives than commercial technologies.

Several options for industrial symbiosis, as presented above, could be possible for SSAB Strip Products. During the interviews biomass gasification, district heating and ethanol fermentation were discussed. There are large quantities of energy flows, with varying energy quality, at SSAB Strip Products, that are not recovered today, and theoretically some of this energy can be used in biorefinery plants. Edberg and Kärsrud (Interview, 2009) believe however, that it is more energy-efficient to use the energy-rich process gases from steel production internally at SSAB Strip Products, than to export the gases. They regard the ULCOS’ Top Gas Recycling Blast Furnace as a future option for steelmaking at SSAB Strip Products.
This blast furnace produces less excess energy, since the off-gases are recycled back to the blast furnace.

Today, SSAB Strip Products sends excess process gases to LuleKraft AB’s CHP plant and receives electricity and steam back. The CHP plant’s exhaust gases are used to dry biomass pellets and represent the only refining of biomass currently integrated into SSAB’s operations (Interview Edberg, 2009).

7.2.2 Business perspective

Compared to the pulp and paper industry there are not many technological options within the scope of this report for the iron and steel industry. SSAB is not very interested in technologies for refining and use of biomass, as they feel there is limited opportunity for the large-scale replacement of reducing agents with biomass. During the interviews, discussions were more active regarding scrap replacing iron ore as a raw material, DRI, ULCOS’ Top Gas Recycling Blast Furnace and CCS, but these technologies are not within the scope of this report. The main reasons for the limited interest in technologies for refining and use of biomass seems to be the amount of biomass that would be needed to, for example, replace the pulverised coal in the blast furnace with pulverised charcoal. In addition, this kind of change in the process could also affect the quality of the products before the process is optimised for this new reducing agent (Interview Edberg, 2009; Interview Kärsrud, 2009). The unwillingness to change the process is understandable and could be perceived as SSAB relying on its core capability, more specifically the technical systems dimension, for its competitiveness. All the representatives interviewed considered it a better option to use excess energy-rich gases from the steel production internally at SSAB and use biomass in a CHP plant compared to using the excess gases in the CHP and biomass at SSAB. On the other hand, Kärsrud (Interview 2009) states that SSAB are willing to adjust their excess energy products (pressure, temperature etc) according to a customer’s requirements. However, it seems unlikely that the initiative for this kind of cooperation would come from SSAB.

By improving efficiency in its energy system SSAB is aiming to reduce its carbon dioxide emissions by 2% through to 2012, which corresponds to 130,000 tonnes of carbon dioxide (SSAB, 2009). Due to the low energy content of biomass and the high temperatures required in the processes at SSAB the technologies within the scope of this report offer a low contribution to mitigation of carbon dioxide emissions in this industry, which is a further reason for the low level of interest in them. Uncertainty regarding the development of carbon dioxide prices and the global raw material markets will probably have the greatest impact on SSAB’s
choice of development path (Interview Edberg, 2009: Interview Kärsrud, 2009). SSAB is therefore very concerned that legal instruments in relation to carbon dioxide emissions would lead to uneven competition on the global steel market.

7.2.3 Policy perspective

The main instrument which concerns the industry is the EU emission trading scheme. It should be mentioned that European iron and steel producers have in recent decades been concerned about competitiveness even in the absence of any costly climate measures. This sector has a long record of being unable to compete with foreign imports and has filed anti-dumping suits with the European Commission to prevent supposedly “unfair” pricing strategies from companies outside the European Union.

The EU ETS

Carbon dioxide emissions from the iron and steel industry can be divided into direct and indirect emissions. The majority of direct greenhouse gas emissions come from plants that convert iron ore and coal to iron and steel in the process where ore is reduced in blast furnaces. Indirect emissions come from installations that base their production on scrap and use electricity in their internal processes.

Using similar logic, the costs for this sector in relation to the EU ETS can be both direct as a result of the need to buy permits, and indirect – the industry is forced to pay a higher price for electricity. However, the industry has so far resisted the obligation to buy permits and based their reason for this on the fact that this situation would have a severe negative impact on their competitiveness on the global market (EUROFER, 2008). The industry, if obliged to purchase its permits, has no chance of surviving in the EU and this will result in the overall detrimental effect for the environment since it will result in the relocation of iron and steel producers to the countries where the obligation to buy permits is absent (EUROFER, 2008). As in the case of other industrial sectors studied here, the products from iron and steel plants are international commodities and their price is set on the global market. This means that the industry cannot pass on any of the additional costs incurred as a result of the directive (Interview Jernkontoret, 2009).

Another argument is technological constraints in relation to the carbon abatement in iron and steel making. Our respondent has stated that the production process is at a mature stage and further technological improvements are not expected in the near future (Interview Jernkontoret, 2009). Given that the emission trading scheme will not bring about the technological breakthroughs desired by policy-makers, only
higher production costs (Interview Jernkontoret, 2009) may force the industry to relocate.

Finally, replacement with renewable energy sources does not seem to be an optimal option for the iron and steel industry. Charcoal, for instance, played an important role in this industrial sector in the 18th and 19th centuries as a fuel for production processes. The demand for charcoal was so high that it was one of the main reasons for the loss of forests in some countries in Europe. The reversal of this trend first came about when the use of wood and charcoal as combustible fuels was replaced by the use of fossil energy sources (Peck, 2001:9). Today use of biomass as an alternative energy source to decrease the use of conventional fuels in processes in the iron and steel industry has limited potential with its low energy intensity in comparison with fossil fuels. According to our respondent, attempts to revive the use of biomass in the industry’s processes will bring about a recurrence of the deforestation problem that was experienced in previous centuries; “It is unrealistic that half of the forest resources is used for the iron and steel industry” (Interview Jernkontoret, 2009). Furthermore, such a move will leave other industries without biomass; industries where it could deliver more benefit from the point of view of a reduction in greenhouse gases (Interview Jernkontoret, 2009).

During the second trading period (2008-2012) all the iron and steel producers received 100% of their permits free of charge. In the new trading period, in the absence of global sectoral agreement within the Kyoto framework, permits will continue to be distributed free of charge, at least for producers who employ best technologies (Interview Jernkontoret, 2009). For the period beyond 2020 the industry has great hopes for the ULCOS (Ultra-Low CO2 Steel) project which should bring about carbon dioxide-free steel production processes in which carbon capture and storage and substitution of carbon-intensive fuels with natural gas would play an important role (Interview Jernkontoret, 2009; EUROFER 2008; see also earlier discussion on ULCOS in section 5.2.1.).

7.3 Oil refining industry

The oil refining industry has long experience of processing and utilisation of petroleum fuels. In the transition into a renewable economy it could play an important role with extensive experience in processing and converting petroleum oil products into valuable fuels. Oil refineries have the opportunity to use existing equipment and there are several options for an oil refinery to increase the use of the renewables discussed in this section e.g. co-feeding of biomass, stand-alone units or production of hydrogen from biomass-derived feedstocks. Co-feeding of
biomass-derived feedstocks with crude oil at an oil refinery could decrease dependency on petroleum feedstocks. Petroleum-derived feedstock differs from biomass-derived feedstock and this may necessitate a change in the way the refinery is operated and managed.

7.3.1 Technological perspective
Biomass feedstock for an oil refinery can come from three categories of biomass: cellulosic biomass, starch- and sugar-derived biomass and triglyceride\textsuperscript{15}-based biomass (Huber and Corma 2007). Before co-feeding biomass in a petroleum process the biomass must be converted into gaseous or liquid products. Three main refining technologies could be used to convert biomass from cellulosic into liquid, including hydrolysis, fast pyrolysis and liquefaction. Torrefaction could also be an alternative. These technologies were further described in the Background section. Gasification followed by standard syngas reaction is also an alternative for conversion into liquid products i.e. Fischer Tropsch synthesis. The wax that is produced as a by-product to the Fischer Tropsch diesel can be converted into diesel in a modified hydrocracker. It is also possible to modify conversion units to produce biodiesel by means of transesterification.

Catalytic cracking of biomass-based feedstock
Bio-oils can be upgraded to transportation fuel that meets existing fuel standards by using catalytic cracking to reduce their oxygen content and molecular size and improve their thermal stability. The products from catalytic cracking of biomass feedstocks are: Hydrocarbons (aromatic, aliphatic), water-soluble organics, water, oil-soluble organics, gases (CO\textsubscript{2}, CO, alkanes) and coke. Fluid catalytic cracking (FCC) is the most widely used catalytic cracking process for converting crude oil into lighter fractions in a petroleum refinery.

One advantage of fluid catalytic cracking is that no hydrogen is needed and atmospheric pressure operation is sufficient. This offers both processing and economic advantages compared to hydrotreating, which uses hydrogen gas to convert the bio-oil. Nevertheless, low yields from hydrocarbons and high yields from coke may occur under fluid catalytic cracking of biomass-derived feedstocks. For more information about the fluidised catalytic cracker process see Huber and Corma (2007). (Huber and Corma, 2007)

\textsuperscript{15} Nationalencyklopedin: “Triglycerides are the major form of fat. A triglyceride consists of three molecules of fatty acid combined with a molecule of the alcohol glycerol.”
The catalytic cracking process is still under development as an alternative for the oil refining industry in the transition to biomass-based feedstock. A driving force for this technology is that no hydrogen is needed, which otherwise is a large indirect energy consumer. A stable and sufficient hydrogen balance is necessary in times when hydrogen demand at refineries is on the increase. With this option, the existing infrastructure can be used (Huber and Corma, 2007; Huber et. al., 2007). Only modifications at existing units are necessary. According to Huber and Corma (2007) UOP\(^{16}\) has investigated catalytic cracking and found that vegetable oils can be used to produce a similar yield of gasoline and olefins as vacuum gas oil. However, the chemical reactions are not yet fully understood.

In the interview, Preem did not bring up this technology as an alternative for biomass feedstocks. However, with more research and investigations this alternative could be an interesting option for them.

**Hydrotreating of biomass-based feedstock**

By hydrotreating bio-oils, liquid alkanes with high cetane numbers\(^{17}\) (80-100) and good fuel properties can be produced (Marker, Petri et al. 2005; Huber and Corma 2007) i.e. green diesel. As with catalytic cracking, the existing infrastructure can be used. Only small modifications are necessary and fuel product can meet existing fuel standards.

In contrast to the hydrotreating of petroleum, which is used to remove sulphur, nitrogen and metals from petroleum products, hydrotreating of biomass feedstock gives rise to new families of highly exothermic, hydrogen-consuming reactions due to the high oxygen content in biomass feedstock. (Høygaard et al., 2009)

The hydrotreating process occurs by adding hydrogen under high pressure over a catalyst bed. All hydrotreaters work along the same principles; feedstock is mixed with hydrogen, which is often produced in the reforming unit, and heated up to 260- 430°C. All reactions are exothermic and in order to control the heat release, effluent from the first catalytic bed can be mixed with fresh feedstock. This procedure eliminates the risk of corrosion and controls the heat released from the exothermic reactions. After the reactor, the effluent is cooled and the oil feed and

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\(^{16}\) UOP is an international supplier and licensor of process technology, catalysts, adsorbents, process plants and consulting services to the petroleum industry [www.uop.com](http://www.uop.com).

\(^{17}\) *Cetane number*, a measure of the ignition value of a diesel fuel oil (Oxford English Dictionary, 2009)
gas mixture is separated in a product separator. The stripped gases are normally recycled back to the reactor, using a recycle gas compressor. The hydrotreating reactor can be fed with different bio-oils produced from cellulosic as well as vegetable plants. The driving forces for the hydrotreating of biomass are requirements and/or incentives from society to increase the renewable content in transportation fuels, improved functionality compared with first-generation biofuels, feedstock flexibilities and no limits for blending with mineral oil products. (Høgaard et al., 2009; Interview Nyström, 2009)

The hydrotreater has significant indirect energy use due to the consumption of hydrogen. The reactions related to the biomass require more hydrogen, which increases the demand for hydrogen significantly when biomass feedstock is used as feedstock for the production of green diesel. The hydrogen demand could be reduced if a thermal pre-treatment step takes place before the reactor. (Gevert, 2009)

In 2010, Preem will start producing diesel with a 30% renewable content in a modified mild hydrocracker unit. The figure below shows a schematic description of the process. This unit will have a capacity of 330,000 m$^3$ of diesel and 100,000 m$^3$ of this will be produced from raw tall oil diesel (Karlsson and Nyström, 2009). The raw tall oil diesel is produced from raw tall oil, which is a by-product in the Kraft pulp production and supplied to Preem through Sunpine AB. Karlsson and Nyström (Interview 2009) regard hydrotreating as a good option since it is not based on a raw material that competes with food production, it has good fuel properties, there is no limit on how much it can be blended into fossil diesel and no modification of existing engines or infrastructure is necessary. The diesel with a 30% renewable content will be produced at Preem and sold as summer diesel since the fuel will not have acceptable cloud point\textsuperscript{18} characteristics for a Swedish winter climate. Preem’s production of green diesel requires ~115,000 tonnes of raw tall oil/year, which corresponds to 1.15 TWh/year.

If the total diesel demand in Sweden were to include a 30% renewable content a rough calculation shows that it would require over 1.6 million tonnes of raw tall oil each year or 16 TWh/year. For calculations and assumptions see Appendix 3. In comparison, the total production of raw tall oil is 230 k tonnes per year in Sweden and varies according to the Kraft pulp mill production (Interview Nyström, 2009).

\textsuperscript{18} Cloud point Chem., the temperature at which an oil or other liquid begins to cloud on cooling (DOE, 2009)
One aspect not highlighted in the interview, but no less important, is that hydrotreating of bio-oil is a very hydrogen-consuming process. Implementing this process results in an increase in hydrogen demand. The demand depends on the quality of the diesel produced, e.g. European diesel is less hydrogen-consuming than Swedish environmental class 1 diesel since more aromatics are allowed. However, despite quality biomass, hydrotreating of bio-oils consumes more hydrogen than current hydrotreating of petroleum feedstocks (Interview Nyström 2009). It is therefore important to take hydrogen production into consideration when implementing biomass-based feedstock. Calculations of carbon dioxide emissions are not included in this study although they must be considered in order to determine whether bio-oil based feedstock represents a reduction in carbon dioxide emissions compared with current operations with fossil fuel. A Well-to-Wheel study is being developed for the tall oil diesel (Interview Nyström, 2009). Hydrotreating reactions are exothermic and bio-oil feedstock increases the heat released and forms water and carbon dioxide during the reaction, which could deactivate the catalyst (Høgaard et al., 2009).

Neste Oil is another oil refining company that has created renewable diesel production (NExBTL) by modifying an existing hydrotreater (Neste Oil). Another
difference compared to the process used at the Preem refinery is that the NExBTL produces 100% renewable diesel from palm oil.

The demand for hydrogen is also on the increase due to the increased conversion and production of lighter products, increased processing of sulphur-rich crude oil, stricter sulphur specifications in fuels and generally improved product qualities.

**Hydrogen production from gasification**

At present, there is a considerable demand for hydrogen in petroleum refining operations in different units, such as the hydrotreater and in the hydrocracker. In addition, transformations into production of green diesel could necessitate an increase in hydrogen demand as discussed in the section on bio-oil hydrotreating above. To meet the increasing demand for hydrogen and at the same time introduce biomass into the petroleum processes, one option could be to produce hydrogen through on-site gasification of biomass. One such pathway could be to co-feed by-products such as coke with biomass in a gasification plant for hydrogen production (Berntsson et al., 2008). It is also possible to use bio-oil from biomass as feedstock for a gasification plant. According to a study by Spat et al. (2003) gasification of pyrolysis oil can be cheaper than both low- and high-pressure gasification of solid biomass. However, it is important to bear in mind that hydrogen production from pyrolysis oil requires more biomass. According to Berntsson et al (2008) 80% more biomass is required for pyrolysis compared with solid biomass gasification. The pyrolysis case also generates more by-products that can be utilised. Otherwise, the efficiency of the process is low. The problem with the relatively high ash content in biomass during gasification is not a problem during gasification of pyrolysis oil i.e. the ash is already separated. There are many possible gasification technologies although the number of alternatives decreases if hydrogen production is the main product wanted. The gasification technology is described further in the background section. Both gasification of solid biomass and bio-oil are exothermic systems that produce excess heat. Gasification of bio-oil produces more net steam at higher temperatures (Rodhin 2008) that can be utilised as steam for electricity generation or heat for district heating.

In a study by Rodhin (2008) 548 tonnes/day dry biomass (1.2 TWh$_{\text{biomass}}$/year) are needed to meet the demand of 0.79 TWh$_{\text{biomass}}$ /year of hydrogen through gasification of biomass at Preemraff in Gothenburg. If hydrogen is produced by gasification of bio-oil$^{19}$ instead the need of biomass

$^{19}$ In this case the bio-oil is produced by pyrolysis
feedstock is 822 tonnes dry biomass/day (1.7 TWh_{biomass}/year). In this study the biomass was assumed to come from branches and residue from forestry and sawmills. According to the study, the total amount of available biomass in an area close to the studied refinery was 1,561 tonnes/day, sufficient to satisfy biomass demand. A rough estimate was made with the same efficiency that was used in Rohdin (2008) for calculations at the Gothenburg facility and a scale-up to meet a need of 4.29 TWh_{biomass}/year of hydrogen at Preemraff in Lysekil shows that more than 6.30 TWh_{biomass}/year is needed. For gasification using bio-oil from pyrolysis the biomass demand would be 9.4TWh_{biomass}/year. A rough estimate made by Berntsson et al. (2008) showed a biomass demand for gasification of biomass to hydrogen of 10,000 tonnes/day (18.2 TWh_{biomass}/year).

Preem has studied pyrolysis of biomass but concluded that it is not an option due to contamination of the fuel (Interview Karlsson and Nyström, 2009). A pilot test reveals low efficiency and it would be difficult to use the excess heat if the pyrolysis process took place in areas with a low population density, i.e. with a small district heating network.

In the case of biomass, no fully commercial system is running at present to produce synthetic gas and as the calculations in this section show it is not feasible to produce all hydrogen from biomass in a more complex refinery with high hydrogen demand. The cost of gasification technology is high and the supply of biomass feedstock is uncertain since the demand is high and the refinery process must have a continuous flow of hydrogen to supply the process. Gasification of charcoal is another possibility that is not investigated in this report.

However, the total demand for hydrogen does not necessarily need to be met by gasification. This could still be an option for increased replacement of fossil fuels and a way for future increased hydrogen demand to be met in the process.

When hydrogen is produced from biomass-based feedstock it is important to understand that most of the green product is in the carbon dioxide emissions since the molecular weight of a carbon atom is 12 times the molecular weight of a hydrogen atom. In this case it could be more interesting to produce fuels or materials from biomass where the carbon atoms are in the product.

**Gasification of natural synthetic gas for hydrogen production**

Another possibility for a refinery to substitute fossil fuel is by indirect use of biomass for production of hydrogen in a steam reformer. In this case indirect use of biomass means that the biomass is converted into synthetic natural gas (SNG) by
gasification outside the refinery and the gas is later used to produce hydrogen at the refinery. Indirect use of biomass via a natural gas grid means that a refinery has the possibility to use renewable feedstock without any modifications at the refinery. Mixing renewable synthetic gas with natural gas in the grid provides users with partly renewable feedstock and at the same time it excludes the uncertainties regarding supply of biomass. It also excludes problems at the refinery due to the high acid number of biomass, although that would be reflected in the price of bio-SNG. At the moment there is no synthetic natural gas produced from biomass in the natural grid that Preem can buy. There are therefore no clear rules for a trading system regarding the renewable part of the gas grid. This issue must be addressed before it is possible for the refinery to use this option for the replacement of fossil fuels. A steam reformer can still be implemented and operated with natural gas feedstock but then without a renewable incentive.

Today Preem produces hydrogen as a by-product in a naphtha reformer although hydrogen is becoming increasingly the main product as gasoline demand is declining (Interview Karlsson and Nyström, 2009). There is a surplus of gasoline in Europe and decreasing demand from the US, which can be explained by the increase in the use of diesel and ethanol, smaller cars, change in lifestyle etc. Preem is therefore considering implementation of a steam reformer for hydrogen production.

A rough calculation of the biomass demand for hydrogen production through steam reforming of synthetic natural gas indicates a biomass demand of 1.75 TWh/year to meet the hydrogen demand at Preem in Gothenburg and a biomass demand of 9.49 TWh/year to meet the hydrogen demand at Preem in Lysekil. The steam reformer would produce 0.1 TWh/year and 0.6 TWh/year of HP steam at the respective refineries. More calculations and assumptions can be found in Appendix 3.

**Fischer Tropsch liquids**
Another option for use of biomass at refineries is gasification followed by Fischer Tropsch synthesis from syngas. Crude Fischer Tropsch liquids can contain some oxygen and olefins which are easily removed by hydrotreating (Marker, Petri et al. 2005). Products from the Fischer Tropsch process are naphtha, diesel and wax. To maximise the amount of diesel the wax can be is cracked in a mild hydrocracker (moderate pressure and temperatures are needed) to produce diesel and naphtha. This technology is still being developed and more research and practical operations are needed before this technology is an alternative for the refining of biomass. The naphtha fraction can be converted into gasoline through isomerisation to improve
the octane number. The cold flow properties of the FT-diesel paraffins can be improved through isomerisation (Interview Nyström, 2009).

7.3.2 Business perspective

Within the scope of this report the technological options for the oil refining industry are few compared with the pulp and paper industry and many compared with the iron and steel industry. Preem’s strategy consists of two parallel paths: developing the Gothenburg refinery towards the production of green diesel and increasing the complexity of the Lysekil refinery for the refining of crude oil (Interview Karlsson, 2009a; Interview Nyström, 2009). This strategy includes plans for a biomass-based hydrotreating process at the refinery in Gothenburg. During the interview hydrogen production from gasification and hydrogen gasification by using synthetic gas were also discussed. Preem regards hydrotreating as a step between first generation renewable fuel and second generation, which is based on gasification. Since biomass is a limited resource Preem’s strategy is a 30% blend of green diesel into fossil diesel. Although tall oil is the first biomass-based raw material Preem is investigating other options e.g. used oils and oil from algae (see background section 5.4 for more information about algal oil), although Preem emphasises that palm oil is not an option due to the difficulty estimating its impact on sustainable development (Interview Karlsson, 2009a; Interview Nyström, 2009).

The attitude at Preem is completely different from both Södra and SSAB. Preem recognises biomass as a new raw material for their processes and a business opportunity and it seems eager to be an early mover in the market for green diesel. Karlsson (Interview 2009a) and Nyström (Interview 2009) regard it as a matter of survival for Preem AB, since the demand for renewable fuel by society in general and in the EU, particularly on a large share, has become very strong in the past two years. Even within the company interest in renewable raw materials is increasing and Karlsson (Interview 2009a) admits that “it feels good to be working with these issues, which have a completely different approach within the company”. The fact that many European oil refineries of the same size as the Preem refinery in Gothenburg have faced bankruptcy lately is also a factor that further justifies the ambition of having a strong position on this new market. The fact that Preem only has limited links to the crude oil market makes a transition to renewable raw material easier (Interview Karlsson, 2009a; Interview Nyström, 2009).

This ambitious strategy has implications for Preem’s organisation. One example of this is that the Refinery Development Group, where both Karlsson (Interview 2009a) and Nyström (Interview 2009) are members, have been commissioned to investigate and develop fuels from biomass. The company is also establishing R&D
activities in this area, which is a new phenomenon for the company (Interview Karlsson, 2009a; Interview Nyström, 2009). The independence of the Refinery Development Group gives Preem the character of an ambidextrous organisation.

As regards the development of gasification, Karlsson (Interview 2009a) and Nyström (Interview 2009) explain that they regard cleaning after the gasification process as the greatest barrier to this technology. This is a huge challenge which demands co-operation by industry, universities, scientists, the government etc. Preem is involved in several clusters or alliances for the development of new technologies in this area, e.g. Nordic Climate Cluster, Sunpine AB, Business Region Göteborg, The West Sweden Chamber of Commerce and Industry and Chalmers University of Technology. Preem, together with E.ON and Perstorp, is interested in starting a Swedish gasification platform. The company also takes an active part in discussions with e.g. GoBiGas and pulp and paper companies such as Södra and SCA. Preem perceives alliances as necessary for the development of gasification, as they are necessary for risk reduction and exchange of competencies.

Karlsson (Interview 2009a) and Nyström (Interview 2009) think that many different technologies and fuel alternatives will be used in the future. Except for the technological options described above they see potential in methanol, DME, electric vehicles and hydrogen and fuel cells. Despite this they believe crude oil will remain an important feedstock for liquid fuels since it has the advantage of being an efficient energy carrier and it is cheap. Preem’s strategy for Lysekil is thus to adjust this refinery for optimal use of crude oil, since they believe there will continue to be a market for liquid fuel from crude oil. Besides technological issues, legal instruments play an important role in the development of renewable fuel and especially for Preem’s strategy for the refinery in Gothenburg. The present trend is to a large extent driven by the Fuel Quality Directive and Preem’s strategy could thus be seen as response to this in line with ecological modernisation.

7.3.3 Policy perspective

The increasing dependence on oil in countries outside the European Union, projected oil shortages and the explosive growth in demand for transport fuels from developing countries make the oil refining sector a particularly fascinating area of analysis. The EU is making attempts to reduce its dependence on oil through the establishment of mandatory targets for biofuels for 2020 (CEC, 2008). Furthermore, Sweden has its own ambitious vision of being independent of fossil fuels in the transport sector by 2030, a period not too far off (Regeringskansliet, 2008).
Oil refineries have been the subject of increased attention, not only in relation to them being part of a problem but also being part of a solution to climate change and this is an image that many oil companies attempt to mediate in public. The empirical evidence analysed by Anshelms and Hansson (forthcoming) suggests, for instance, that there is a striking convergence of ideas and goals in the documents prepared by environmental NGOs and certain multinational corporations in the oil sector regarding solutions to major environmental problems. Both call for political regulation and investment in cleaner technologies, which may suggest that oil companies are prepared to move along the path of radical transformation, displace present-day activities and reorient their production in a more sustainable direction.

This image coincides with the presentation of the industrial sector that the respondent from SPI presents at the beginning of the interview. In his words, oil refining is “an industry that is on the path towards the renewable area” (Interview SPI, 2009). However, once questions of a more practical and technical nature are asked, the responses suggest a very different reality. The analysis below aims to reveal in more detail future and present strategies in this industrial sector as a response to policy measures from the European Union. The data obtained during the interview was complemented by the information acquired from the official statements from EUROPIA. EUROPIA is one of the main channels through which the Swedish Petroleum Institute conducts its lobbying in relation to policy-making in the EU and the views of both organisations converge on matters that concern the policy instruments studied (Interview SPI, 2009).

In relation to the European goal of a low-carbon economy, the oil refining sector is mainly subject to two European directives, the purpose of which is to reduce carbon dioxide emissions. Like other industries discussed in this report, oil refineries are affected by the EU Emission Trading Scheme, revised in December 2008. The sector is also subject to the proposed amendments to the Fuel Quality Directive, which in its present form lays down a reduction in life-cycle greenhouse gases for the fuels produced by refineries.

The EU ETS
While not denying the necessity of taking action in relation to greenhouse gas emissions (EUROPIA, 2008), this industrial sector has opposed the obligation to buy permits and lobbied on the European level against this prospect, citing a variety of reasons. Both in its position paper on the proposed directive and in the course of an interview, the industry representatives revealed concern with the fact that the EU ETS imposes an unjust burden on a sector that has already gone a long way to minimising its GHG emissions in comparison to other industrial sectors.
whose emissions continue to increase (EUROPIA, 2008; EUROPIA, 2007; Interview SPI, 2009). The economic costs in conjunction with the ETS will result in a reduction in the investment that is necessary for GHG abatement measures at the processing units (Ibd. 2008). Furthermore, the imposition of caps on its emissions will place the industry at a competitive disadvantage on a world market since producers in the same branch outside the EU are not facing similar costs (EUROPIA 2008; Interview SPI, 2009). Prices for their products are determined internationally and not in the EU market and companies in the oil refining sector do not have the possibility of passing on additional costs imposed on them as a result of the ETS scheme.

A further reduction in carbon dioxide in different refining processes appears to be problematic (Interview SPI, 2009). The trend in fact is for development to be moving in the opposite direction as the crude oil that is delivered to markets today is of a much inferior quality in comparison to the oil that was used for refining in earlier decades (Interview SPI, 2009). Once oil reservoirs have been in use for some time the oil that is left has a higher sulphur content (“sour” oil) and is in general heavier (EIA, 1999). This situation requires more energy-intensive and “severe” (Ibd. 1999:27) processes during refining which eventually lead to higher emissions of carbon dioxide. Converting heavy oils into lighter transport fuels requires energy (Interview SPI, 2009). Furthermore, in order to reduce the sulphur content in the end-products, natural gas or naphtha should be used in the special process and this in turn also contributes to growing carbon dioxide emissions (Interview SPI, 2009). This situation progresses as the discovery of new reservoirs of crude oil becomes a challenge. For these reasons refineries will increase their carbon dioxide emissions and not reduce them (Interview SPI, 2009).

“Carbon leakage” – migration of carbon dioxide emissions to the countries outside the EU Emission Trading Scheme – is “a fact before it has taken place” according to the respondent from the SPI (Interview SPI, 2009). In the light of the described negative effects that the industry claims will take place as a result of the effect from the trading scheme, the sector has succeeded in negotiating an exemption which in practice implies that installations which satisfy certain benchmark criteria will be allocated emission permits free of charge during the coming trade period.

The Fuel Quality Directive
Unlike the Emission Trading Scheme, which is an obvious example of a piece of legislation in the spirit of ecological modernisation, the Fuels Quality Directive is a traditional “command-and-control” piece of legislation. The recently revised directive establishes binding targets for the refining industry in the form of a
percentile reduction in carbon dioxide. Its provisions in relation to climate measures (the directive also sets EU-wide specifications in relation to transport fuels) require fuel suppliers to decrease their lifecycle GHG emissions in the fuels they produce by 6% beginning in 2011 (see Article 7a of the directive). However, the directive offers considerable leeway for producers with regard to the strategy for achieving this goal. More particularly, the refinery operators may choose to either reduce carbon dioxide emissions in their industrial processes or they may opt to resort to the use of biofuels by blending them into the produced fossil fuels.

The reader must be made aware that this directive does not impose any extra requirement on the oil refinery sector if one considers the fact that this industry already falls under the regime of tradable permits under the EU ETS Directive. Theoretically, both directives may work in a mutually supportive way if emissions are reduced during the production of fuels at the installations since it will in turn reduce the costs associated with the purchase of permits.

As has been discussed earlier, the quality of oil that refineries will need to deal with in the coming years predetermines the unavoidable rise in the level of emissions of carbon dioxide. At the same time, technology has reached its maturity and further reductions below the current levels are almost impossible (Interview SPI, 2009; EUROPIA, 2007). That is why representatives from the interest organisations in Sweden and in Brussels are in no doubt that the objectives of the Fuel Quality Directive will be met through the blending of biofuels into the fossil fuels produced at the refineries (Interview SPI, 2009; EUROPIA, 2007). Furthermore, the Fuel Quality Directive sets stricter standards for sulphur content in the fuels produced. As has already been discussed above, this requires more energy and contributes to the increase in carbon dioxide emissions (Interview SPI, 2009).

In addition to these two facts there is also another reason for the projected increase in emissions. The industry currently finds itself in a very intricate situation. Both inside the EU and Sweden there is a growing imbalance between the import of diesel and the export of gasoline (EUROPIA, 2008; Interview SPI, 2009). Refineries use their full capacity to refine diesel, where demand is constantly growing in the European Union. At the same time, gasoline is an unavoidable by-product of these refinery processes and its demand is falling.

The investments that are planned by the industry are related to this EU-wide trade imbalance – to increase the cracking capacity that is responsible for the production of more diesel fuel from crude oil (EUROPIA, 2008). Only refineries that will be
able to refine sourer and heavier oils are predicted to survive in the coming decades (Interview SPI, 2009).

As for the production of fuels for the transport sector from feedstock that is not fossil, there are not many alternatives. According to our respondent, the industry’s main option at present is the use of biomass in the form of vegetable oils (BtL) (Interview SPI, 2009). In the course of the conversation it became apparent that the representative for the SPI believes that intense discussions at international, European and national level in relation to the unsustainability of biofuels, their competition with food, limited amounts of available feedstock and long-awaited European sustainability standards as to which biofuels can be considered sustainable – all seem to have the effect of steering the industry away from involvement in biomass projects. Tall oil currently appears to be the only available feedstock for refineries that does not compete with food and its use can be defined as sustainable since it is a by-product of the pulp and paper industry. However, its attractiveness is limited by its extremely limited availability. What is clear is the fact that its limited availability cannot solve the problem of transport fuels even in one region in Sweden. “Tall oil cannot save the world”, states our respondent (Interview SPI, 2009).

As for all other ways of producing transport fuels at the refineries, there are still many barriers, especially technical ones, that need to be overcome before they can be commercialised (Interview SPI, 2009). For instance, an alternative feedstock such as algae is being considered although its application is still at the early research stage, which means commercial application, if it materialises at all, is years away (Interview SPI, 2009).

The low energy density of biomass is another sobering factor. The respondent from the SPI, for instance, raised the qualities of oil as a decisive factor for not going over to the production of renewable transport fuels. In comparison to other raw energy sources, “oil is phenomenal…it is easy to transport and it contains great amount of energy per quantity… oil is an ideal raw product” (SPI 2009). This information casts doubts on the idea that refineries are seriously considering biofuels as their “new oil” (Eikeland, 2006). The industry representatives accept the fact that there will be a gradual reduction in the use of gasoline and diesel in private transport in the coming years as different alternatives come to the market, but does not believe that the transport infrastructure can be changed within a very short space of time (Interview SPI, 2009).
Overall, the representatives of the SPI and EUROPIA are of the opinion that the problem of GHG emissions in the transport sector should not burden the refining sector as emissions from refining processes represent only 15% of emissions from transport fuels. The other 85% are emissions from vehicles as a result of the combustion process in the engines (Interview SPI, 2009; EUROPIA, 2008a). It is therefore the transport sector that should be responsible for addressing the challenge of GHG reductions.

In the context of the incentives that are available today to address the problem facing the transport sector and the narrow focus of legislative measures on biofuels, the current transport infrastructure is unlikely to change in the near future. As long as private vehicles, and especially trucks and other heavy vehicles, depend on fuels from refining processes, the future of the industry is safe, secure and bright. This sector’s efforts will probably result in adopting measures directed at more efficient use of fossil fuels. There are currently several ongoing research projects dealing with efficiency measures for installations. In the short run, however, the emissions from refinery installations are set to increase (Interview SPI, 2009).

**7.4 Summary – Technological Perspective**

Many of the refining technologies described in the previous section are possible in more than one of the industries studied. All the opportunities are summarised in
Table 4 below. Ethanol fermentation and anaerobic digestion to produce biogas are refining processes which demand heat that can be integrated into all three industries since they all have available excess heat. Ethanol produced in the fermentation can either be used as a reducing agent in the iron and steel industry, in the oil refining industry to blend with gasoline or be sold for other purposes. Gasification, pyrolysis and liquefaction are also technologies that have potential in all industries. For the pulp and paper industry these three technologies offer an opportunity for the industry to refine its by-products but for the other two industries they offer a supply of green feedstock.
Table 4 Summary of opportunities for refining technologies and the products from the different processes in each industry

<table>
<thead>
<tr>
<th>Refining technology</th>
<th>Kraft pulp mill</th>
<th>Oil refinery</th>
<th>Iron and steel industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification</td>
<td>SNG from by-products</td>
<td>SNG for hydrogen production</td>
<td>SNG as a reducing agent</td>
</tr>
<tr>
<td></td>
<td>Fischer Tropsch diesel from by-products</td>
<td>Fischer Tropsch diesel</td>
<td>Hydrogen</td>
</tr>
<tr>
<td></td>
<td>DME from by-products, BLG</td>
<td>Hydrogen</td>
<td></td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>Bio-oil from by-products</td>
<td>Bio-oil as feedstock for diesel or hydrogen production</td>
<td>Bio-oil as a reducing agent or fuel</td>
</tr>
<tr>
<td></td>
<td>Same as pyrolysis</td>
<td>Same as pyrolysis</td>
<td>Charcoal as a reducing agent</td>
</tr>
<tr>
<td>Liquefaction</td>
<td>Same as pyrolysis</td>
<td>Same as pyrolysis</td>
<td>Same as pyrolysis</td>
</tr>
<tr>
<td>Transesterification</td>
<td>FAME</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaerobic digestion to biogas</td>
<td>Export of excess heat</td>
<td>Export of excess heat</td>
<td>Export of excess heat and methane as a reducing agent</td>
</tr>
<tr>
<td>Second-generation ethanol production</td>
<td>Export of excess heat</td>
<td>Export of excess heat</td>
<td>Export of excess heat and ethanol as a reducing agent</td>
</tr>
<tr>
<td>Algal fermentation</td>
<td>Algal oil as feedstock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific technologies</td>
<td>Lignobooost</td>
<td>Green diesel through hydrotreating of bio-oils</td>
<td>Drying of biomass for pellet production</td>
</tr>
<tr>
<td></td>
<td>Drying of biomass for pellet production</td>
<td>Green diesel through catalytic cracking of bio-oils</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tall oil and methanol for export</td>
<td>Green diesel through hydrocracking of bio-oils</td>
<td></td>
</tr>
</tbody>
</table>
Some of the results from implementation of the technologies in the different industrial sectors are summarised in 5-7. The results for the pulp and paper industry are based on that this sector can import the same amount of biomass that they can today, but that might not be the case. In a future market there might be other actors willing to pay more for the wood products currently used by the pulp and paper industry.

Pyrolysis from biomass to produce charcoal used as a reducing agent, replacing pulverised coal at SSAB Strip Products in Luleå, would require dry wood imports of around 7.5 TWh/year, corresponding to 13-25% of the increased in the supply of Swedish biomass. Gasification to supply the oil refining process with hydrogen gas would demand, in the case of Gothenburg, 1.2 TWh/year and it is theoretically possible to meet this demand with residue from sawmills and forestry (Rohdin, 2008). If instead hydrogen gas supply is to be met with biomass at the refinery in Lysekil it would require around 6.3 TWh/year, corresponding to 11-21% of the increase in Swedish biomass supply in 2020. For pyrolysis to produce hydrogen gas the demand for biomass is higher for the facility in Lysekil, but in the same range for the facility in Gothenburg. Due to the need for a totally new infrastructure, security of supply and competition for biomass, the alternatives that demand a significant increase in the import of biomass are not likely to occur on a full scale in the beginning. However, this does not exclude the possibility that part of the fossil coal or hydrogen could be replaced by biomass-derived equivalents. Gasification to supply SSAB Luleå with sufficient amount of SNG to replace one-third of the pulverised coal as a reducing agent would require 2.93 TWh_biomass/year, corresponding to 5-10% of the increase in Swedish biomass supply in 2020. To supply Preem Gothenburg and Lysekil with a sufficient amount of SNG to cover the hydrogen gas demand would require 1.76 TWh_biomass/year and 9.49 TWh_biomass/year respectively, corresponding to 3-6% and 17-30% of the future Swedish potential for increasing biomass supply. This is an alternative to hydrogen production from biomass and pyrolysis of charcoal.

Tall oil for refining by Sunpine for export to Preem for the production of diesel will be delivered from Swedish kraft pulp mills. In the initial phase Preem will produce 330,000 tonnes of diesel with a renewable content of 5-30%, corresponding to a maximum of 1.15 TWh/year of raw tall oil. If all diesel used in Sweden in 2007 were to be replaced with diesel containing 30% tall oil, it would require 16.47 TWh raw tall oil per year. Compared with the theoretical amount of tall oil that Södra, Värö could deliver (0.12 TWh/year) this is 135 times as much, and seven times the total Swedish tall oil production (2.3 TWh/year). A new biomass feedstock, other than tall oil, needs to be found to produce large amounts of green diesel. As
discussed in the business perspective in section 7.3.2, algal oil or used oils could be a future alternative.

Table 5. Summary of the biomass demand for the increased use and refining of biomass in the pulp and paper industry. The biomass demands are also expressed as a percentage of the Swedish potential for increased supply of biomass in 2020 (30-56.5 TWh).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Main product</th>
<th>Biomass</th>
<th>% of future increase in biomass supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignoboot</td>
<td>Lignin</td>
<td>4.06 TWh/yr black liquor, intermediate product</td>
<td>0%</td>
</tr>
<tr>
<td>Gasification</td>
<td>0.46 TWh/yr SNG</td>
<td>0.83 TWh/yr solid biomass</td>
<td>1-3%</td>
</tr>
<tr>
<td>Black liquor gasification</td>
<td>2.30TWh/yr DME</td>
<td>4.06 TWh/yr black liquor, intermediate product + 1.04 Twh bark</td>
<td>2-3%</td>
</tr>
<tr>
<td>Pellet production</td>
<td>Pellets</td>
<td>0.11 TWh/yr falling bark, solid biomass</td>
<td>0%</td>
</tr>
<tr>
<td>Anaerobic digestion to biogas</td>
<td>Biogas</td>
<td>3.85 GWh/yr sludge from process waste water plant</td>
<td>0%</td>
</tr>
<tr>
<td>Electricity production</td>
<td>0.45 TWh/yr electricity</td>
<td>steam from recovery boiler</td>
<td>0%</td>
</tr>
<tr>
<td>Export of tall oil</td>
<td>0.23 TWh/yr tall oil</td>
<td>7.8 TWh/yr biomass, by-product from pulp production</td>
<td>0%</td>
</tr>
<tr>
<td>Export tall oil (Värö)</td>
<td>0.12 TWh/yr tall oil</td>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>Export of methanol</td>
<td>24.5 GWh/yr methanol</td>
<td>7.8 TWh/yr biomass, by-product from pulp production</td>
<td>0%</td>
</tr>
</tbody>
</table>

20 KAM2 – Model for a market pulp mill: 8,330 h/year operating time, 700,000 tonnes (Adt) pulp production, 7.8 TWh biomass import/year
Table 6. Summary of the biomass demand for increased use and refining of biomass in the iron and steel industry. The biomass demands are also expressed as a percentage of the Swedish potential for increased supply of biomass in 2020 (30-56.5 TWh).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Main product</th>
<th>Biomass</th>
<th>% of future increase in biomass supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrolysis</td>
<td>2.6(^{21}) TWh/yr charcoal</td>
<td>7.5 TWh/yr dry wood</td>
<td>13-25%</td>
</tr>
<tr>
<td>Anaerobic digestion to biogas</td>
<td>1.76(^{22}) TWh/yr biomethane</td>
<td>1.50 million tonnes of organic MSW</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.15 million tonnes of garden waste</td>
<td>n.a.</td>
</tr>
<tr>
<td>Ethanol fermentation</td>
<td>0.41(^{23}) TWh/yr ethanol</td>
<td>1.31 TWh/yr cellulose feedstock</td>
<td>n.a.</td>
</tr>
<tr>
<td>Gasification</td>
<td>1.76(^{24}) TWh/yr SNG</td>
<td>2.93 TWh/yr dry wood</td>
<td>5-10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.1 (^{25}) billion Nm(^3) synthesis gas/year (&lt;5% non-reducing gases)</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

\(^{21}\) Replacement of the pulverised coal, used at SSAB Strip Products, with pulverised charcoal for injection into the blast furnace

\(^{22}\) Replacement of 1/3 of the pulverised coal, used at SSAB Strip Products, with biomethane for injection into the blast furnace

\(^{23}\) Excess heat from an iron and steel plant is used in an ethanol fermenting plant with production of 70,000 m\(^3\) ethanol/year (in this case the ethanol is not used in processes at the iron and steel plant)

\(^{24}\) Replacement of 1/3 of the pulverised coal, used at SSAB Strip Products, with SNG for injection into the blast furnace

\(^{25}\) Gasification plant integrated with a DRI plant producing 1.6 million tonnes of DRI/year
Table 7. Summary of the biomass demand for increased use and refining of biomass in oil refineries. The biomass demands are also expressed as a percentage of the Swedish potential for increased supply of biomass in 2020 (30-56.5 TWh).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Main product</th>
<th>Biomass</th>
<th>% of future increase in biomass supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification (Gothenburg)</td>
<td>0.79&lt;sup&gt;26&lt;/sup&gt;TWh/yr H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>1.16 TWh/yr dry wood chips</td>
<td>2- 4%</td>
</tr>
<tr>
<td>(Lysekil)</td>
<td>4.29&lt;sup&gt;27&lt;/sup&gt; TWh/yr H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>6.3 TWh/yr dry biomass</td>
<td>11-21%</td>
</tr>
<tr>
<td>Pyrolysis (Gothenburg)</td>
<td>0.79&lt;sup&gt;28&lt;/sup&gt;TWh/yr H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>1.2/1.3 TWh/yr dry wood chips</td>
<td>2 – 4%</td>
</tr>
<tr>
<td>(Lysekil)</td>
<td>4.29&lt;sup&gt;29&lt;/sup&gt;</td>
<td>6.4/9.4 TWh/yr dry wood chips</td>
<td>17 – 31%</td>
</tr>
<tr>
<td>Hydrotreater&lt;sup&gt;30&lt;/sup&gt;</td>
<td>100,000 m&lt;sup&gt;3&lt;/sup&gt;/ yr green diesel (30% renewable)</td>
<td>1.15 TWh/yr raw tall oil</td>
<td>55 % of total raw tall oil in Sweden</td>
</tr>
<tr>
<td>Synthetic natural gas (100% renewable) (Gothenburg)</td>
<td>0.79&lt;sup&gt;31&lt;/sup&gt;TWh/yr H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>1.76 TWh/yr biomass</td>
<td>3-6%</td>
</tr>
<tr>
<td>(Lysekil)</td>
<td>4.29&lt;sup&gt;32&lt;/sup&gt; TWh/yr H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>9.49 TWh/yr biomass</td>
<td>17- 32%</td>
</tr>
</tbody>
</table>

The biomass demand for some of the technology alternatives in the table above is not possible to summarise due to the use of the same feedstock or production of the same product. In the oil refinery, for example, the biomass demand for hydrogen production is calculated to satisfy the hydrogen demand at the facility and therefore only one technology alternative at a time could be an option. To illustrate the amount of biomass required in the industries studied we have summarised the

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<sup>26</sup> Gasification + purification (Rodhin 2008)
<sup>27</sup> Some efficiency for gasification + purification as (Rodhin 2008) has been used to estimate the biomass demand in Lysekil.
<sup>28</sup> Pyrolysis + purification (Rodhin 2008)
<sup>29</sup> Some efficiency for gasification + purification as (Rodhin, 2008) has been used to estimate the biomass demand in Lysekil.
<sup>30</sup> 98vol% efficiency
<sup>31</sup> Assuming 60% efficiency in the SNG process and 3.26G cal/1000 Nm<sup>3</sup> H<sub>2</sub> in the steam reformer
<sup>32</sup> Ibid
highest demand for the technology alternatives\textsuperscript{33} that are possible to combine. Compared to the future increase in biomass supply in Sweden in 2020, it would demand 70\%. Only a few facilities are included here and the results show that they would consume a large proportion of the biomass considered to be available for new actors in 2020.

7.5 Business perspective on biomass use 2050

Even though current policies try to stimulate use of biomass as a source of energy and several technological options are possible, none of the case companies believes that biomass will increase significantly in the Swedish energy system over a longer time perspective, towards 2050. The reason for this is that biomass is regarded as a limited resource and neither SSAB nor Preem believe that biomass could represent a large-scale substitute for the currently used fossil fuel. This is also underlined by the comparison with the calculations in this study and the potential for increased biomass supply in Sweden, in 2020, see Table 5.

Many of the representatives mentioned that CHP based on biomass feedstock combined with CCS could offer higher carbon dioxide emission mitigation potential than biofuels and what will be regarded as the most optimal future use of biomass is still very uncertain. Other renewable energy sources, e.g. solar cells and wind power, and alternative technologies, e.g. carbon capture and storage, are believed to have greater potential than biomass. Despite the somewhat pessimistic view of biomass potential as a future feedstock the representatives we met at both Södra and Preem are happy that the companies they represent have chosen to become actively involved in environmental issues.

In 2050, Södra hopes that they still can use biomass fibres for the production of pulp as they do today and that the use of cellulose fibres has expanded into the production of composite material, clothes, chemicals and medicine (Interview Andersson, 2009). If it were up to Södra, only residues and excess energies would be converted into energy carriers and not cellulose-based feedstock.

SSAB does not believe that any technological options for biomass refining or use will be implemented at their facilities in 2050. They instead believe that before

\footnotesize{\textsuperscript{33} The technology options included are: black liquor gasification at Södra Cell Värö, substitution of the fossil injection coal with charcoal at SSAB Strip Products, production of SNG to satisfy the demand at Preem’s refinery in Lysekil.}
2050 surplus energy from SSAB’s operations will be integrated with surrounding energy systems and biomass could be one of several feedstocks in this system (Interview Kärsrud, 2009). Another future option is different kinds of industrial symbiosis and SSAB feels it would be positive if other businesses could use their surplus energy. Both Edberg (Interview 2009) and Kärsrud (Interview 2009) believe that SSAB will develop ULCOS’ top gas recycling blast furnace with carbon dioxide capture and storage before 2050, which could reduce carbon dioxide emissions by 50%.

Preem’s strategy for remaining competitive is to develop fuels for the existing infrastructure using existing refineries modified for the flexible production of green diesel and fossil fuel. Preem fears that competition for biomass as a feedstock will be more important in 2050 than competition between operators and their core capabilities. This could be one reason for their ambition to become an early mover on the green diesel market and to establish relationships with biomass suppliers.

As mentioned in the section about the business perspective at Preem, present rigorous laws and policies affecting the oil refinery industry have offered Preem a business opportunity and the company is modifying its hydrocracker unit for green diesel production. This operation will be based on tall oil from Södra and Sveaskog, which together with Preem are owners of Sunpine AB. Södra and Preem have previously operated on two separate markets, but will now be part of the same value chain. Södra is interested in buying green diesel from Preem for its own vehicles as part of their strategy of becoming independent of fossil fuel (Interview Andersson, 2009). This would thus make Södra both a supplier and a customer in the same supply chain. The development of the relationship between Södra and Preem is interesting and opens up speculation about the future. Södra’s ability to deliver tall oil seems to be driven by the development of technologies that contribute to the replacement of oil in the lime kiln and Södra’s ambition to become independent of fossil fuel. However, Preem aims to sell this diesel on the market and position itself as a supplier of green fuel (Interview Karlsson, 2009a; Interview Nyström, 2009), which does not prevent Södra from buying Preem’s green diesel on the market. At present, tall oil seems to be Preem’s only biomass-based feedstock and Preem is working actively to find other alternatives. Before this is accomplished Preem must be careful and be mindful of preserving good supplier relationships.

7.6 Policy perspective

Like any technological transition, a move towards a low carbon economy is a long and arduous process. In contrast to earlier industrial transformations (for more on
technological transitions see Smil, 2008), the current industrial revolution is distinct since it is to a large extent policy-driven. Laws and policies have an important role to play in encouraging transformative processes within industry and steering the process of industrial transformation towards decarbonisation and sustainability. The analysis of relevant laws in the context of industrial strategies is therefore essential to gain an insight into the adequacy of the legal instruments studied to bring about this change.

Below are the results from the analysis of the adequacy of the three European directives studied in relation to technological transformations.

7.6.1 The EU ETS does not push industries beyond efficiency measures

The EU ETS is central to all the industrial sectors analysed here. Industry is the source of both direct and indirect emissions of greenhouse gases which are responsible for the worsening of the problem of climate change.

However, the analysis of the industrial response to the effects created by the ETS regime suggests that the application of the provisions of the directive creates winners and losers. To begin with, there is a major difference between how two groups of producers are affected by this trading scheme: those who operate within closed domestic or regional markets, such as electricity producers, and those whose products compete on the international markets. The former have the advantage of being able to pass on costs associated with the purchase of allowances; the latter lack this possibility (Interview SFIF, 2009; CEPI, 2008).

Furthermore, this particular effect of the directive allows considerable leeway for industrial operators that cannot pass on the costs to argue the case for the “carbon leakage” exemption – a situation in which the EU ETS possibly leads to an untenable financial situation for European producers, forcing them to relocate their business activities to areas not constrained by the regulation of greenhouse gases. Due to the fact that the rest of the world outside the EU is not committed to climate change policy, the producers not located within the EU market immediately gain comparative advantage over the European producers as the former do no have extra costs associated with the purchase of carbon allowances. Representatives from the iron and steel and oil refining sectors all voiced concern about the imminent reduction and even loss of their competitiveness (Interview SPI, 2009; Interview Jernkontoret, 2009) and are active in persuading the Commission to grant exemptions from the EU ETS. The pulp and paper industry is founded on utilisation of energy from forest-based raw materials and it is therefore in a more
advantageous position to reduce its emissions through the replacement of fossil fuels with biomass-based fuels in its combustion processes. However, it appears that even within this sector there is a desire to benefit from safeguards. This is due to the fact that different installations within this sector are not affected homogeneously by the EU ETS since pulp and paper companies use different processes and even different raw materials to produce the same product and this in turn affects their consumption of energy and carbon dioxide emissions. This is despite the fact that they are in a unique position through their better prerequisites for switching to the use and refining of more biomass.

The above arguments are taken seriously by the Commission and it is working on a list of sectors deemed to be exposed to a significant risk of “carbon leakage”. The list will be published at the end of 2010. It is speculated that in order to address industrial concerns about the loss of competitiveness and possible carbon leakage, industry-specific standards, known as “benchmarking” criteria, will be established in relation to sectors whose competitiveness is seriously affected (CEC, 2009a). These criteria are set against the efficiency indicators of the best performers within each industry. It is planned that independent auditors will set a referential value of GHG emission per unit of production as a condition under which producers will avoid the need to purchase permits. An incentive will thus be created for individual companies to approach these efficiency standards in order to lower or avoid additional costs associated with carbon trading.

In summary, the analysis of the Emission Trading Scheme “in action” does not seem to push the industries in focus in a radically innovative direction and its scope and magnitude are to a large degree defined by the issue of competitiveness for the industries concerned. The threat of “carbon leakage” serves as a persuasive argument for regulators to introduce special exceptions. Without denying the necessity of an emission trading scheme for the mitigation of global warming, the industrial operators claim that similar schemes should exist globally and be linked to the European system (Interview Jernkontoret, 2009; Interview SPI, 2009). This solution is not only better for industries, they argue, but possibly also for the whole European economy and the climate. But until such international schemes are in place, permits should be allocated to industries 100% free of charge (Interview Jernkontoret, 2009; Interview SPI, 2009).

The industrial sectors studied in this report claim (often in combination with the “carbon leakage” argument) that they are not able to pass on the cost incurred as a result of the emissions regime to the price of their final products due to the fact that their prices are set on the global markets. However, the reverse situation would
have combated the very aim of the directive, which is to set the cost for carbon and thus internalise environmental externalities and eventually push the industries into sustainable use of energy in their processes. The fact that certain producers have the possibility of reclaiming their costs by setting higher prices signifies that there are no real incentives for them to change their “business as usual” practice.

Another common argument is the “maturity” of the technology. Industrial representatives claim that the opportunities to reduce their greenhouse gas emissions are limited since technology sets boundaries for any further improvements. Investment cycles are long, lasting for about two decades, and investment costs are enormous (Interview Jernkontoret, 2009). Only those producers that do not make use of the best available technology still have GHG reduction potential in their installations and these are the only producers that should be obliged to purchase allowances. The rest of the producers should either receive them free or be compensated.

The Commission’s list of industries which are considered to be threatened by “carbon leakage” will be ready by the end of 2010 (CEC, 2009a). Both oil refineries and iron and steel plants are likely to be listed there and in the case of these sectors allocation of allowances will continue to take place for free during the third emission trading period according to the benchmark criteria discussed above. In other words, only industrial operators that are behind the best performers will be required to pay for their right to emit. This suggests that the original aim of the directive to compel industries to reduce their GHG emissions is softened by the exceptions introduced for industrial sectors exposed to international trade.

### 7.6.2. The Fuel Quality Directive promotes biofuels

Rather than encouraging industry to invest in low carbon projects, the provisions of the Fuel Quality Directive boost the use of biofuels. This situation occurs not only because of the discretion that is inherent in this directive but also because it allows fuel producers to choose between taking measures to reduce GHG emissions at any stage in the production of their fuels or by simply blending in biofuels. In fact one of the aims of the directive is “to facilitate the achievement of current and future Community biofuel targets” (CEC, 2007) and this confirms the statement by Stavos Dimas in the press release that it “will open the way for a major expansion of biofuels”.

In fact, the response of the oil refining sector also confirms that the only way in which the requirements of the directive will be met is through the increased blending of biofuels. No measures involving the reduction of carbon dioxide
emissions in its industrial processes will be taken as it is impossible to further reduce emissions from the production and refining of oil, especially viewed in the context of stricter standards for sulphur established by the very same directive (Interview SPI, 2009; see also discussion above 7.3.3.). As carbon dioxide emissions are predicted to rise, this will require larger volumes of biofuels to meet the requirements in the directive.

7.6.3. The Renewable Energy Directive

This directive obliges Member States to raise their share of renewable energy sources by 2020. However, the Community is neutral about the choice of the energy mix with one notable exception. There is a disproportionate focus on biofuels in the EU, regarded as being a very important solution to the problems in the transport sector. At the same time biofuels are at the heart of intense environmental and economic debates with scientific evidence pointing to different knock-out effects as a result of their production (e.g. EEA 2006; EEA 2008). The Community has attempted to address these discourses by elaborating on the sustainability criteria in the revised directive. Otherwise, the Community is firm in the Renewable Energy Directive about its ambitious 10% target for 2020 in relation to transport fuels and the previously analysed Fuel Quality Directive further strengthens and supports this objective.

The question of whether reliance on biofuels is appropriate as a solution to global warming is addressed in numerous studies. There are several alternative ways to support the transport system but these are not encouraged equally in the EU. Depending on how sustainably these alternative sources of energy are produced (either electricity or hydrogen), they offer a better solution to the problem of GHG emissions in the transport sector. However, none of these other alternatives paths are supported in European energy and climate policy.

The disproportionate focus on the promotion of biofuels can be explained by attempts in the Community to address its growing oil dependence. It is relevant to point out here that the EU’s dependence on this energy source is predicted to reach 90% of its overall oil supplies in 2030 (CEC 2000) and in its green paper “Towards the European strategy on the security of energy supply” the Commission points out the need for a special emphasis on a series of measures to address this particular challenge.

Biomass is the only renewable energy source that can be converted into liquid fuels which are in turn compatible with the existing socio-technical infrastructures. Even if they differ from engine to engine, liquid transport fuels are suitable for use by the
majority of vehicles on the market. Policies which do not encourage other alternatives but focus on advancement of the use of biofuels sustain current socio-technical structures in the transport sector rather than bring about radical technological transformation.

7.6.4. Concluding remarks about the studied legal instruments
The policy perspective in this report strives to gain an insight into the adequacy of the forthcoming directives under the EU climate and energy package to bring about technological transformation in the processes in the iron and steel, pulp and paper and oil refining sectors. The results presented below are based on the analysis of the relevant legal instruments and the information obtained from the interviews with the representatives of these industries’ interest organisations.

For reasons of time and the magnitude of factors studied in this project, it can be suggested that the amount of data that was obtained is rather unconvincing if very thorough and far-reaching conclusions are to be made in relation to the policies studied here. Attempts are made, however, to generalise certain findings. A number of factors have been established that cast doubt on whether the legal instruments studied here are sufficient to initiate profound transformative processes within the industries concerned.

It is argued by many (Smith et al., 2005) that any effective regime transformation requires a concrete articulation of its direction. While the EU in general has set highly ambitious targets, the analysis of the expected effect of directives suggests that they are more of an aspirational nature, encouraging insignificant innovations along the established technological pathways rather than promoting the structural changes in established socio-technical systems that are actually required. The flexibility and the desire to achieve the environmental objectives in the most cost-efficient way – two elements that are in line with ecological modernisation – allow the dominant business interests to exploit the policy-formation processes in which they participate to their own advantage, although with different outcomes.

Laws that come out of Brussels and which are directed at specific industries are often influenced and even moulded by these very industries. As a result, the legislative instruments are softened so as to protect the competitiveness of the European industrial sectors open to international trade. The interplay between dominating market industries and the legislators in the process of identifying the objectives of industrial greening thus results in policies that reproduce the current socio-technical regime.
Oil refineries and iron and steel producers, as sectors exposed to global competition, have succeeded in affecting the scope of the emission trading scheme by invoking their vulnerability to carbon leakage due to the inability to pass on the cost of the carbon constraints to the price of their products. This has resulted in a policy response that has taken the form of benchmarking according to which best performers receive free allowances.

There is a possibility that some installations, even within the pulp and paper industry, will also be able to benefit from these safeguards. However, it is difficult to speculate on this further since the facts regarding benchmarking will only become clearer once the Commission is ready with all the details in 2010. In general, the pulp and paper sector has concerns in relation to the loss of competitiveness in connection with the increase in demand for biomass, and thus a fall in price, as a result of the transposition of both the EU ETS and Renewable Energy Directives.

The existing legislative framework seems to promote a status quo in the energy system instead of pushing it in a sustainable direction. The EU environmental policy has gone through a transformation process in recent decades and now it is increasingly integrated with the economic policy of the European Union with the outcome that climate policy goals are subordinated to the goals of other EU polices, such as economic competitiveness or security of supply. This situation leads to policies that either attempt to achieve environmental goals without harming the competitiveness of the established industries or to promote energy sources that can in the short term replace energy sources such as oil, with a risk of disruption in its supply.
8 Discussion

The pulp and paper industry can function as a producer of a green product that can be used as feedstock in oil refinery or iron and steel industry. Hence, refining technologies can create new forms of collaboration between these industries. Examples of current collaboration between Södra and Preem are described in Section 4.3.2. The advantages of such collaboration are geographical proximity since transportation costs are reduced. The distance between the co-operators is especially important if excess heat is transported. If the distance is too great the solution is not profitable i.e. the heat losses and distribution network costs increase with distance.

If it is possible to use an existing infrastructure for refining biomass the costs are reduced and the switch to biomass feedstock is more likely to occur. The companies are highly dependent on supply assurance and if the purpose of a refining technology is to supply a feedstock for their own production purposes, the technology must be reliable and have a high level of operational reliability. Industrial symbiosis where excess energy from one industry can be used in biorefinery processes can be a possible option for all industries studied. However, in this study is Industrial symbiosis only described in more detail for the iron and steel industry but the concept can be applied in the pulp and paper as well as the refining industry.

Investing in the biorefining concept the industries explore new fields which demand new knowledge. Knowledge and experience between the different industry fields can be enhanced and exchanged through collaboration and investment in a common facility can be an option for the development of biomass refining technologies. Barriers that gasification technologies, Fischer Tropsch synthesis and production of second-generation ethanol need to overcome are high investment cost and lack of operational reliability since they are still under development.

The market for biomass is global. The price of biomass and consequently expected profits for the purchasers may have an impact on where it will be used in the future. The prospective biomass users have an advantage on the global market if they are located onshore, since transportation costs can be reduced if large ships are used. It is also a financial advantage if biomass suppliers are located near the users. All the facilities studied are located onshore with the possibility of using existing harbours. The case companies therefore have access to the global biomass market and are not limited to the potential increase in biomass supply in Sweden.
If more facilities in different industrial sectors were included in the study the result would probably indicate that it is not an option that all industries increase their use of biomass feedstock. Even when taking into account access to the global biomass market the biomass will probably be limited to supplying industries with the most efficient use of biomass in terms of both cost and environmental impact. As indicated by the company representatives, bio fuel or bio energy can only partly contribute to the mitigation of climate change, other solutions are also necessary. This is a consequence of the limited resources of biomass while at the same time the most efficient use of biomass from an environmental perspective is still under debate.

Additionally, it is worrisome that while there is a wide consensus within the European Union as far as the need to address the problem of global warming, it appears that the instruments designed to achieve this aim appear to have an insignificant effect on the future strategies of the industries studied in this report as far as the use of biomass but even other climate-friendly energy sources.

A few words need to be said about the way this project is done. The case study approach applied means that the extent of the study is limited and the results from the technological and business perspective cannot be generalised to other facilities or companies within these industrial sectors. The results from these perspectives would benefit from further study of a larger number of companies and facilities within the same sector. The analysis from the policy perspective is relevant to the entire industrial sector studied in this report but cannot be generalised to other industrial sectors. Part of the analysis regarding legal instruments was based on the opinions of the representatives’ interest organisations, which may suggest that conclusions are based on data that is not very satisfactory, even though attempts were made to increase the reliability of information by employing additional sources of information. A larger number of interviews used in investigations from the business and policy perspectives would enhance the reliability of the results from these perspectives.

In the analysis of technological options and business strategies the limited scope for biomass refining and use implies that other carbon dioxide emission-mitigating technologies and strategies are not included. Particularly in the case of SSAB this limitation contributes to quite meagre results and the analysis would benefit from wider scope.

A more detailed analysis, including modelling of energy balances, costs, process integration and carbon dioxide emissions, given different future market scenarios,
is necessary in order to compare the technological options. From the climate perspective, biomass should be used where it leads to the greatest reduction in greenhouse gases and a more detailed analysis could indicate the most efficient use of biomass in the system studied.

There are a number of important factors that facilitate industrial transition towards increased refining and use of biomass which have not been examined in this report. In general, the price of fossil fuels is an important controlling factor that affects the market share of renewable fuels. It can be speculated that in the future higher costs for carbon dioxide emissions will introduce more effective incentives for more efficient use of biomass.
9 Conclusions
The aim of this study was to investigate the role of the three energy-intensive industrial sectors in relation to the increased refining and use of biomass. The industries studied have different prerequisites and the technological options available diverge to a great extent for different industries. Several of the options demand large amounts of biomass and this is a barrier to implementation. For example, replacement of fossil injection coal with charcoal at SSAB Strip Products would require 7.5 TWh of biomass per year. To satisfy the hydrogen demand at Preem’s oil refinery in Lysekil it would require 9.5 TWh of biomass per year. The biomass demand for concurrent implementation of these two alternatives corresponds to 30-57% of the increase in the Swedish bioenergy potential in 2020. From the interviews with the case companies it can be concluded that the companies studied can contribute significantly to the development of technologies that are in line with their core capabilities, while the development of technological options that require a change in their core capabilities is more limited. This discovery is further supported by the finding that the EU directives relevant to this report do not push industrial operators beyond efficiency measures along established technological lines. These legislative instruments, designed in the spirit of ecological modernisation, encourage the most cost-effective technologies and processes for the abatement of greenhouse gases relevant to each industry. But, they do not appear to be sufficient to raise the cost of carbon dioxide emissions, which contributes to a situation where incentives to make different biomass-based technologies economic are not present on the market. In a longer time perspective none of the case companies believes that biomass will have increased significantly in the Swedish energy system in 2050. The companies claim that biomass is too limited a resource and only can only contribute in part to the necessary replacement of fossil fuels.

More detailed conclusions for the three perspectives are presented below. The research question for the technological perspective is: What are possible technological options for increased refining and use of biomass in the industrial sectors studied and what are the driving forces and barriers to these options?

This study shows several possibilities for increased refining and use of biomass in the three energy-intensive industries studied. However, many of the options demand technologies that are still being developed and imply major economic risks which are barriers to implementation. Most of the technological options can be implemented more easily in the pulp and paper industry as production is based on biomass. There is potential for increased internal use and refining of intermediates
and by-products for conversion to energy or material products. Further technological options that depend on increased import of biomass could take advantage of the existing distribution system, storage possibilities on site, expertise in handling biomass and a strong position on the biomass market.

Options for the increased use and refining of biomass in the iron and steel industry include substitution of part of the coke in the blast furnace. An industrial symbiosis together with a biorefinery could also be an interesting option for this sector. Replacement of the coke would require large amounts of biomass.

There are several options for the oil refining industry to replace fossil feedstocks and at the same time use the existing infrastructure. One such technology is hydrotreating of bio-oil into green diesel. However, production of biofuels demands large amounts of biomass and it is not feasible to satisfy the total diesel demand by using biomass feedstocks. Another interesting option for the refining industry is to produce hydrogen from biomass-based feedstock, which also demands large amounts of biomass.

The technological options for the iron and steel industry and oil refining presented in this study require large amounts of biomass; two of the options for oil refining require up to 30% each of the potential of increased use of biomass for energy production in Sweden in 2020. However, the market for biomass is global. Facilities located onshore have a financial advantage in the opportunity to import biomass at a lower price due to lower transportation costs.

The research question for the business perspective is: What are the case companies’ views on implementation of technologies for increased refining and use of biomass and biomass use in the future?

All Södra’s operations are based on biomass feedstock and there are many technologies available for achieving greater efficiency in existing processes as well as adoption of new technologies that fall within the scope of this study. Södra’s primary interest, today and in the future, is to improve the pulp production process. However, the company is also interested in using new technologies for producing non-cellulose-based products as long as they do not compete with pulp production. Södra plans to supply tall oil for the production of green diesel. This makes Södra and Preem members of the same new value chain although they are currently operators on distinctly separate markets.
There are not many technological options for SSAB and the company does not seem to be interested in investing in facilities not related to its core capabilities. The reason for this is that SSAB regards biomass as too limited a resource, especially compared to coal, which the company uses today. SSAB believes that their excess heat will be used to a greater extent in the future and they are optimistic about investors being interested in industrial symbiosis.

The attitude at Preem is completely different from both Södra and SSAB. Preem recognises biomass as a new feedstock for their processes, which offers a business opportunity. Preem seems eager to be an early mover in the market for green diesel. Their strategy consists of two parallel paths: to develop the Gothenburg refinery towards the production of green diesel and to increase the complexity of the Lysekil refinery for refining crude oil. Tall oil will be the initial feedstock for green diesel production. Since tall oil is a limited resource, Preem is searching for other raw materials and is making plans for flexibility in further production investments. As mentioned, Preem and Södra will be linked in the supply chain for green diesel production. Preem is also part of several other alliances which they regard as important, especially for the development of biomass gasification technology.

The research question for the policy perspective is: *Are the European directives discussed in this report sufficient to stimulate profound changes in industries and to bring about industrial transformation in the form of a low carbon economy?*

It appears that the legal directives studied are guided by the principle of ecological modernisation, according to which environmental protection can be combined with economic development and continued industrialisation. A combination of the goals for economic growth and climate protection appear, however, to be difficult to implement in practice. A price tag on greenhouse gas emissions is needed to transform industrial practices and put business on the path towards technological innovation. However, the European Union appears to have difficulty with this task without seriously undermining the profitability and competitiveness of its industrial sectors.

In general, cost efficiency appears to be the central aspect of the directives studied here. In practical terms, it implies that these legislative instruments strive to achieve the desired goals without harming the competitiveness of the regulated industries. For instance, industrial sectors which are exposed to international competition will not be obliged to pay for permits unless they fail to use the best available technology, which is defined as technology at the level of the best performers in each sector. In other words, the EU ETS appears to be effective in
encouraging industrial laggards to invest in better technologies and transitions are thus limited to existing technological achievements of the best performers instead of pushing business operators towards a more profound transformation of an industrial energy system.

Finally, the fact that the legal instruments directed at the industries studied here not only reflects environmental commitments but also the European Union’s internal concerns and priorities is another disadvantage. For example, the EU’s growing dependency on oil and other fossil fuels and the objective of the Lisbon agenda to become the most competitive economy in the world, often call for short-sighted solutions.
10 Further work

Several starting points for further investigations were identified during the writing of this report. For the three industries studied it would be interesting to carry out more detailed modelling of the suggested technologies to find which parameters will have the greatest effect on future development and the current energy system, given different future markets and political conditions. The results of technology modelling from each industry could then be compared between the industries to evaluate where it would be most suitable to implement biomass-demanding technologies, both in terms of cost efficiency and carbon dioxide emissions. This comparison should also be compared with an analysis of how the suggested technologies are modelled in connection with carbon capture and storage technology in each industry. This study could provide an indication of whether or not carbon capture and storage connected to flue gases would be more efficient in terms of energy use, carbon dioxide emissions and cost.

It would be valuable to combine the modelling with the results from the business and policy perspectives in order gain a deeper understanding of the driving forces and barriers to different technological pathways. A possible future study could expand the business perspective with a larger number of interviews from different companies regarding their views on refining and the use of biomass. The results of this survey could be beneficially combined with an analysis of the most cost-effective and carbon dioxide-mitigating technologies. It could also be valuable to unite a broader business perspective with an analysis of how the prerequisites at the facilities differ, including different external parameters such as proximity to a harbour or a district heating system.

Modelling and optimising different industrial symbioses where biorefineries are connected to energy-intensive industries, can guide investors in locating a new facility. This modelling could be another future option for co-operation, where the three industries in this report can function as case studies. Another factor that would be interesting to study further is the development of alliances, as this appears to be important in the development of technologies for refining and use of biomass.

Finally, it could be a promising area for future study to further explore differences and commonalities between how different industrial sectors at company level respond to legislative instruments by combining technological, business and policy perspectives. This may help to enhance the understanding of the nature of the ongoing industrial transformation and the role of legal instruments in that transformation.
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Appendix

Appendix 1 – Calculations for the pulp and paper Industry

A lot of the calculations regarding the pulp and paper industry use the model kraft pulp mill called KAM2. This a model developed by Innventia (former STFI-Packforsk AB) conducted by Mistra, and used in many previous research projects, for example by Petterson (2009). KAM 2 is a model for a bleached kraft market pulp mill using the best available technology in Scandinavia. This means that it can provide a better picture for a future kraft pulp mill than if an existing facility is used for analysis. The model contains detailed data for energy and material process streams. The figure below shows the material and energy process streams that are relevant to this project.

**A schematic process flow chart of the KAM2 model mill (Pettersson, 2009, modified)**

**Additional data, KAM2:**
Operation time 8,330 h/year
Production of tall oil: 230 GWh/year
Production of methanol: 24.5 GWh/year
Production of sludge: 3.85 GWh/year

Specific data, used to calculate tall oil production:
Production of pulp: 17.7 GJ/t90
Production of tall oil: 1.2 GJ/t90
Assumption: Södra Cell, Värö has the same proportions of pulp and tall oil produced as the KAM 2 mill and the same energy content in the raw material:

\[(1.2/17.7) \times 7.8 \times (\frac{34 \, 000 \, 000}{700 \, 000}) = 0.3 \, \text{TWh}\]

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34 Production of pulp ADt/year at Södra Cell Värö, 2007
Appendix 2 – Calculations for the iron and steel industry

Replacement of injection coal with charcoal at SSAB Strip Products

In 2007 SSAB Strip Products used 340,000 tonnes of pulverised coal for injection into the blast furnace. This is 30% of the total amount of reducing agents, the rest is coke. The heating value of coal is approximately 7.56 MWh/tonne (County Administrative Board35) and for charcoal figures between 7.01 and 7.75 MWh/tonne are reported (Baker, 198236; Fuwape, 199337). Charcoal consists of about 20-25% volatile matter, 70-75% fixed carbon and 5% ash (Baker, 1982) and the typical carbon content for coal (dry basis) is in the 60-80% range (Hong & Slatick, 199438). If coal is equalising with charcoal then one tonne of charcoal powder can replace one tonne of coal powder in the blast furnace process. According to Baker (1982) the yield of charcoal from wood is about 25% by weight on a dry basis. Consequently, the production of 340,000 tons of charcoal demands 1,360,000 tonnes of dry wood (7.5 TWh39). The moisture content of freshly cut wood is commonly 45-50% (Baker, 1982) and thus the annual coal powder demand at SSAB Strip Products corresponds to approximately 2.7 million tonnes of freshly cut wood.

Substitution of 1/3 of the injection coal with biomethane at SSAB Strip Products

Approximately one-third of the weight of the injection coal can be replaced with natural gas (methane) without adding more coke (Interview Edberg, 2009). This accounts for approximately 113,000 tonnes of coal powder. Natural gas consists chiefly of methane ranging between 75% and 99% by volume (Keating, 200740). The theoretical coke replacement factor for coal powder is between 0.5 and 0.99 kg coke/kg coal (lignite and anthracite respectively) depending on the energy and carbon content of the coal (Jaffarullah & Ghosh, 200541). The coke replacement ratio with natural gas is almost equivalent to 0.8 kg coke/m³ methane (Abdel Halim et al. 2009). A mesophilic biogas facility digesting organic municipal solid waste (MSW) with 30% total solids (ts) produces 0.25 kg methane/kg ts and the energy yield is 12 MJ/kg ts (Berglund & Börjesson, 200342). Assuming 113,000 tonnes of natural gas equals 113,000 tonnes of methane the substitution of one-third of the coal powder with biomethane from biogas requires digestion of 1.5 million tonnes of organic MSW/year. The energy content of the methane is 1.7643 TWh. Digesting gardening waste (70% ts) under the same conditions yields 0.14 kg of methane/kg ts or

39 The energy content of dry wood (HHV) is 18-22GJ/tonne
43 The energy value of methane, 39.76 MJ/Nm³, is used.
6.8 MJ/ kg ts (Berglund & Börjesson, 2003\textsuperscript{44}). Substituting 1/3 of the injection coal at SSAB Luleå with biomethane requires 1.15 million tonnes of garden waste. As a comparison, the reactor at Linköping Biogas treats 55,000 tonnes of organic waste per year and has a production of 10 million m\textsuperscript{3} raw biogas with a methane concentration of 60-70\% (Swedish Biogas, 2009\textsuperscript{45}). The feedstock is primarily abattoir and food waste. To support SSAB in Luleå with methane for iron ore reduction would take 26 facilities the size of Linköping Biogas\textsuperscript{46}.

Another alternative is to use SNG as a source of methane. In this calculation SNG is equalised with methane. Gasification plants with a biomass to SNG conversion efficiency of 60\% would require 2.93 TWh biomass in order to produce 1.76 TWh SNG. 2.93 TWh biomass corresponds to 0.53\textsuperscript{47} million tonnes of dry wood. As a comparison, four gasification plants, each with a capacity of 60 MW SNG and an operating time of 7,200 h/year, are required to satisfy the SNG demand at SSAB Strip Products.

**Excess heat used in an ethanol fermenting plant**

Steam produced from excess gases from an integrated iron and steel plant could be used in processes at an ethanol fermenting plant. An ethanol plant with enzymatic hydrolysis, an operating time of 7,920 h and production of 70,000 m\textsuperscript{3} ethanol/year requires 60 tonnes/h of cellulosic feedstock (50\% moisture content). The import of biomass to satisfy the ethanol plant’s demands is 1.31\textsuperscript{48} TWh/year of dry wood and the energy content of the ethanol produced is 0.41\textsuperscript{49} TWh/year.


\textsuperscript{45} Swedish Biogas. <http://www.svenskbiogas.se/sb/biogas/anlagningar> (2009-04-14)

\textsuperscript{46} In this calculation the density of methane, 0.71 kg/Nm\textsuperscript{3}, is used (Berglund & Börjesson, 2003).

\textsuperscript{47} The energy value of 5.5 MWh/tonne is used for dry wood.

\textsuperscript{48} Ibid.

\textsuperscript{49} The energy value of ethanol is 5.89 MWh/m\textsuperscript{3}.
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Energy value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 tonne coal</td>
<td>7.56 MWh</td>
</tr>
<tr>
<td>1 tonne coke</td>
<td>7.79 MWh</td>
</tr>
<tr>
<td>1 tonne LPG gas</td>
<td>12.79 MWh</td>
</tr>
<tr>
<td>1 Nm³ natural gas</td>
<td>38.3 MJ</td>
</tr>
<tr>
<td>1 m³ ethanol</td>
<td>5.89 MWh</td>
</tr>
<tr>
<td>1 m³ wooden chips</td>
<td>0.95 MWh</td>
</tr>
<tr>
<td>1 tonne dry wood</td>
<td>5-6 MWh</td>
</tr>
<tr>
<td>1 tonne charcoal</td>
<td>7.75 MWh</td>
</tr>
<tr>
<td>1 Nm³ coke gas</td>
<td>17.5 MJ</td>
</tr>
<tr>
<td>1 Nm³ blast furnace gas</td>
<td>~3 MJ</td>
</tr>
<tr>
<td>1 Nm³ LD gas</td>
<td>7 MJ</td>
</tr>
<tr>
<td>1 Nm³ methane</td>
<td>39.76 MJ</td>
</tr>
<tr>
<td>1 Nm³ carbon monoxide</td>
<td>12.71 MJ</td>
</tr>
<tr>
<td>1 Nm³ hydrogen gas</td>
<td>12.78 MJ</td>
</tr>
</tbody>
</table>

*Moisture content 30% (air-dried)
Appendix 3 – Calculations for the oil refining industry

Assumptions for calculations of biomass demand for hydrogen production from SNG

The refinery processes in Gothenburg require approximately 30,000 Nm$^3$/h of hydrogen (Rodhin 2008). At the refinery in Lysekil the hydrogen demand is calculated at 162,000 Nm$^3$/h based on an assumption made by Berntsson et. al (2008) of a daily hydrogen demand of 350 tonnes. In the calculations all hydrogen is assumed to be produced in a steam reformer with specifications listed in the table below. All natural gas to the reformer is assumed to originate from biomass gasification and SNG production. The efficiency of SNG production was assumed to be 0.6.

<table>
<thead>
<tr>
<th>Steam reformer properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas feed</td>
<td>3.26 Gcal/1000 Nm$^3$ H$_2$</td>
</tr>
<tr>
<td>Natural gas fuel</td>
<td>0.19 Gcal/1000 Nm$^3$ H$_2$</td>
</tr>
<tr>
<td>Production of excess hydrogen</td>
<td>0.35 Gcal/1000 Nm$^3$ H$_2$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assumptions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen demand at Preemraff. Gothenburg</td>
<td>30,000 Nm$^3$/h</td>
</tr>
<tr>
<td>Hydrogen demand at Preemraff Lysekil.</td>
<td>162,000 Nm$^3$/h</td>
</tr>
<tr>
<td>Operation time</td>
<td>8,760 h/year</td>
</tr>
<tr>
<td>Energy content H$_2$</td>
<td>120 MJ/kg</td>
</tr>
</tbody>
</table>

If all hydrogen at the refineries in Gothenburg and Lysekil was to be produced from biomass-based synthetic natural gas the requirement would be 1.76 TWh/yr and 9.49 TWh/yr of biomass feedstock, respectively. The steam reformer would also produce 0.1 and 0.6 TWh/year of HP steam.

Assumptions for the calculation of tall oil demand

Calculations to estimate the total demand for raw tall oil needed to produce 30% of the total Swedish diesel consumption (including FAME) from tall diesel are based on assumptions from the hydrotreating process at Preem and the tall oil refining process at Sunpine AB, see table below. The total consumption of diesel is based on statistical data from SCB in 2007.

<table>
<thead>
<tr>
<th>Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency of the hydrotreater</td>
<td>0.98 vol %</td>
</tr>
</tbody>
</table>

64 All specifications are taken from a steam reformer supplier at Preem
65 Borel L. and Favrat D., 2005, Thermodynamique et énergétique, Presses polytechniques et universitairs romandes, CH-Lusanne
66 Interview Nyström (2009)
<table>
<thead>
<tr>
<th>Efficiency of the tall oil refining process$^{67}$</th>
<th>0.83 vol%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel demand in 2007$^{68}$</td>
<td>4.67 million m$^3$</td>
</tr>
<tr>
<td>Total production of raw tall oil in Sweden$^{69}$</td>
<td>230 k tonnes/yr</td>
</tr>
</tbody>
</table>

Based on the assumptions stated above, 16.5 TWh/year of raw tall oil is required to replace 30% of the total diesel demand in Sweden, this corresponds to seven times the maximum amount of available raw tall oil from the Kraft pulp and paper mills in Sweden. If Preem produces 100,000 m3/year of green diesel the tall oil demand is 1.15 TWh/yr of raw tall oil, corresponding to 50% of the total raw oil available in Sweden.

The hydrotreating process is a very hydrogen-intensive process and biomass as feedstock increases the hydrogen demand. Depending on the fuel quality, the hydrotreating process with biomass feedstock requires more hydrogen than hydrotreating processes for fossil oils.

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$^{67}$ E-mail conversation with Johan Lundbäck, Sunpine, April 2009
$^{68}$ SCB (2007)
$^{69}$ Interview Nyström (2009)
Appendix 4 – Questions for case company interviews

1. Presentation the project and introduction

2. What is your background and present position at the company?

3. Present strategy
   
   a. What technologies for increased refining and use of biomass has the company evaluated?
   
   b. What technologies for increased refining and use of biomass are the company interested in developing?
   
   c. Why has the company chosen these technologies?
   
   d. How is the company organized to work with these technologies?
   
   e. What is the company’s strategy when it comes to the development of technologies in this field?

4. Hinders and driving forces for the present strategy
   
   a. Which uncertainties have the largest impact for the development in this field?
   
   b. How does the company handle these uncertainties?
   
   c. How is the company affected by policies?
   
   d. How is the company affected by the market?

5. Position 2050
   
   a. How do you think biomass will be used in 2050?
   
   b. How far in the future does the company plan?
   
   c. What do you think will happen in this field at the end this plan?
   
   d. What factors are most important for the development in this field?
   
   e. How will the company go from the present situation to the future situation you describe?
Appendix 5 – Main topics for the interviews with interest organisations

1. Presentation and introduction

2. General questions regarding the interest organisation

3. Questions relating to the industrial response to policies from the European Union in the form of
   a) technological measures or investments
   b) lobbying to influence policy formation or prevent undesirable policy measures

4. Questions concerning the role of the interest organisation as a political player in Sweden

5. Questions concerning the role of the interest organisation as a political player in the EU
Appendix 6 – Biomass potential

Two reviews (Berndes et al. 2003; Lysen et al. 2008) summarised the global potential bioenergy supply in the future. The reviews showed the global potential to range from 0 TWh/year to over 400,000 TWh/year in 2050, see the table below. Ericsson & Nilsson (2006) calculated in another study the European biomass potential for energy production to be 5,000-6,400 TWh/year.

The SFIF has estimated the Swedish potential for increased supply of biomass from forest residues at 20 TWh/year in 2020 (Interview SFIF, 2009). For 2020, estimates of the Swedish bioenergy potential from arable land (including energy crops) range from 10 to 36.5 TWh/year corresponding to an area of 300,000 to < 1 million hectares\(^70\). Consequently, the total Swedish bioenergy potential is between 30 and 56.5 TWh/year in 2020.

<table>
<thead>
<tr>
<th>Studies</th>
<th>Potential</th>
<th>Year</th>
<th>Level</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berndes et al. 2003</td>
<td>27,800 TWh/year - 111,000 TWh/year</td>
<td>2050</td>
<td>Global</td>
<td>A review of 17 studies with the conclusion that the potential for future use of biomass varies between the different studies and the main reason for the difference is that the two most crucial parameters, land availability and yield levels in energy crop production, are very uncertain. There are also different opinions on how to calculate these parameters.</td>
</tr>
<tr>
<td>Lysen et al. 2008</td>
<td>0 TWh/year – 417,000 TWh/year</td>
<td>2050</td>
<td>Global</td>
<td>Analysis of eight recent biomass potential studies. None of the studies include all aspects but give a more detailed insight into the future potential than before. The assumptions between the studies vary and thus the results. Example of variation parameters: technological level of production, agricultural efficiency, population growth and production on abandoned, marginal and residual land.</td>
</tr>
<tr>
<td>Ericsson &amp; Nilsson, 2006</td>
<td>5,000 TWh/year – 6,400 TWh/year (Total) 500 TWh/year - 670 TWh/year (Forest biomass) 190 TWh/year (Crops residues) 4,200 TWh/year - 5 560 TWh/year (Energy Crops)</td>
<td>&lt;2050</td>
<td>Europe</td>
<td>A resource-focused assessment. Includes EU15, ACC10 (Bulgaria, The Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, Estonia, Latvia and Lithuania) and Belarus and the Ukraine. The biomass categories included are: Forest residues and industry by-products, straw, maize residues and energy crops.</td>
</tr>
</tbody>
</table>

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