THE HISTORY AND CURRENT DEVELOPMENT OF FOREST BIOREFINERIES IN FINLAND AND SWEDEN

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Please email updates and corrections to jonas.joelsson@processum.se

Work report of the Forest Refine project

AUTHORS

Jonas Joelsson
Processum Biorefinery Initiative AB
Jonas.joelsson@processum.se

Tero Tuuttila
Kokkola University Consortium Chydenius
tero.tuuttila@chydenius.fi

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Forest Refine

The Forest Refine project is a Swedish/Finnish cross-border co-operation combining knowledge from two disciplines; forestry and chemistry. The purpose of the project is to analyze and improve the raw material supply to biorefineries. Swedish participants are BioFuel Region, Swedish University of Agricultural Sciences (SLU) and Processum Biorefinery Initiative. Finnish participants are Finnish Forest Research Institute (METLA), Centria University of Applied Sciences, Ostrobothnian Rural Institute and Kokkola University Consortium Chydenius. Forest Refine is divided into five sub-projects:

1. Chemical balances and available potentials of forest biomass for biorefineries
2. Effective raw material supply from the forest to biorefineries
3. Chemical and physical requirements of the forest biomass to biorefineries
4. System analyses and energy balances for biorefinery supply chains
5. Outreached activities and partner communication

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National co-financiers in Finland are the **Regional Councils of Ostrobothnia** and **Central Ostrobothnia.**

Preface

This report is the result of a pre-study performed within the Forest Refine project. The primary purpose of the report is to serve as a starting point for coming work within Forest Refine. The field of biorefining is broad, and we do not have the ambition to make a complete description of it. Furthermore, the status of ongoing projects may change rapidly, as well as there may be new projects started. We therefore intend to update this report during the Forest Refine project, and release a new version closer to the end of the project. The reader is hereby invited to contribute with information that adds to and updates the present report.

We are grateful for information already contributed by contacted stakeholder representatives, colleagues within forest refine and K.C. Raghu, who performed an initial survey of the Finnish biorefinery sector (Raghu 2012).

Kokkola, Finland and Örnsköldsvik, Sweden
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The Authors

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Summary

This document is a pre-study report of the Forest Refine project. It provides a screening of ongoing biorefinery activities in Finland and Sweden and a review of the historical development of the forest-based industry. There is no single definition of what a biorefinery is. Therefore, this initial study has had a wide scope, but with a main focus on

> *New, non-conventional processes for refining of forest biomass (i.e. not on conventional heat, CHP, pulp production, etc.), integrated production of multiple products and on the utilization of new forest biomass assortments. Focus is further on value chains containing some steps of decomposition of the raw material on a chemical level, and not on value chains containing only mechanical processing.*

From this review of biorefinery initiatives, it is clear that there is no lack of activities related to biorefining in Finland and Sweden. It appears to be a challenge to bridge the gap from research and development projects to larger-scale, commercial demonstration projects. One reason is the risks inherent in large-scale industrial investments, especially with new technologies. The success of such projects is dependent on a number of parameters outside of the control of the individual project developer.

Much of the information in this report has been collected from web pages and secondary sources, such as reports and news articles. This information may be outdated or incomplete. Future work within the Forest Refine project will follow up and verify the most interesting developments.

Selected projects are listed in Summary table 1.

Summary table 1. A selection of Swedish and Finnish biorefinery activities

Project etc.	(1)	(2)	Description
Hydrolysis & Ethanol			
EPAB	D	S	Pilot plant for cellulosic ethanol production in Örnsköldsvik (~200 m³/yr). Owned by Umeå University, Luleå University, SEKAB.
NBE Sweden	D	S	Development plant for cellulosic ethanol production in Sveg. Owned by NBE Co. Ltd., HMAB, Härjedalen municipality.
ST1	P	F	St1 biofuels are currently producing ethanol from sugar- and starch-containing waste in several plants and are researching technology for ethanol production from cellulose.
Chempolis	D	F	Chempolis Ltd is an R&D company developing biorefinery technologies, specialized in non-food, non-wood raw materials. Has a biorefinery park in Oulu.
Gasification			
BLG DME DP1	D	S	Black liquor gasification demonstration plant. Pressurized (30 bar), oxygen-blown entrained flow gasifier (3 MWth) with a DME demo plant. Technology developed by Chemrec AB.
IVAB	D	S	Pressurized entrained flow wood powder gasification pilot plant (1 MW, 15 bar) in Piteå.
MIUN	D	S	Circulating fluidized bed, indirect gasification (150 kW) with fuel synthesis, Härnösand.
WoodRoll	D	S	Indirect gasification technology demo (500 kW) in Köping. Developed by Cortus.
Chalmers	D	S	A 2-4 MWth indirectly heated gasifier integrated on the return leg of a 12 MWth CFB boiler
Värnamo IGCC	D	S	IGCC demo plant (18 MWth). Planned rebuild for syngas production was cancelled. Mothballed.
NSE Biofuels	D	F	Neste Oil and Stora Enso built a wood gasification demo (12 MWth) in Varkaus. Syngas combusted in lime kiln. The aim was a commercial BTL plant, but it has not been prioritized for NER300 support.
Vaskiluodon Voima	P	F	140 MW gasification plant for CHP under construction in Vaasa
Vallvik biofuel	P	S	Planned black liquor gasification plant with methanol production at the Rottneros mill in Vallvik. Applied for NER300 support but has not been prioritized.
Rottneros biorefinery	P	S	Planned gasification plant for methanol production at the Rottneros mill in Rottneros. Applied for NER300 support but has not been prioritized.
WoodRoll Köping	P	S	Cortus is planning 5 MW gasifier with upscaling to 25 MW in a second step.
Hagfors	P	S	Planned fluidized bed gasifier for methanol production (1000000 t/yr) by Värmlandsmetanol. Uhde selected as technology supplier.
Norrtorp	P	S	Pre-study for 250 MW methanol and SNG plant by Vämlandsmetanol, EON, SAKAB and others.
GoBiGas	P	S	20 MW plant for SNG under construction by Göteborg Energi. An 80-100 MW unit is planned for a second phase. Has been prioritized for NER300 support.
E.ON Bio2G	P	S	SNG plant planned by EON, up to 200 MW. On the reserve list for NER300 support.
UPM Rauma	P	F	Planned gasification/FT plant in either Rauma (Finland) or Strasbourg (France). Strasbourg plant prioritized for NER300 support and Rauma plant on the reserve list.
Ajos BTL	P	F	Planned gasification/FT-plant. Metsä group recently withdrew from the project. Vapo Oy are pursuing the project and are seeking new partners. Prioritized for NER300 support.
Pyrolysis & Torrefaction			
Metso	D	F	2 MW pyrolysis R&D plant in Tampere.
Pyrogrot	P	S	Planned pyrolysis oil plant at the Billerud pulp mill in Skärblacka. Prioritized for NER300 support.
Fortum	P	F	Plant for pyrolysis oil production (50000 t/yr) in Joensuu.
Green Fuel Nordic	P	F	Three facilities for pyrolysis oil production to be built. Expected output 270000 t/yr.
BioEndev	D	S	Torrefaction demonstration plant planned in Umeå.
Torkapparater	D	S	Torrefaction demonstration project located on Gotland.
Preseco	D	F	Bio-char demonstration plant in Lempäälä.
Pulp-mill based			
Domsjö	P	S	Production of specialty cellulose, ethanol and lignin at industrial biorefinery site in Örnsköldsvik.
Södra Cell	P	S	Development of new materials such as specialty cellulose and composite materials. Lignin extraction from black liquor.
SunPine/Preem	P	S	Production of diesel (Evolution Diesel) from tall oil.
Arizona Chemicals	P	S	Production of a range of chemicals from tall oil.
UPM BioVerno	P	F	Planned tall oil based diesel (BioVerno) production facility in Lappenranta.

(1) Demonstration/development (D) or production (P) plant. (2) Geographic location: Finland (F) or Sweden (S).

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Introduction

In its simplest interpretation, refining of biomass – biorefining – is the processing of biomass raw material into more useful and valuable forms. In this sense, virtually any agricultural, food, or forest industry could be said to perform biorefining. However, what we typically mean with biorefining is something that is different from the biomass processing that is performed by these conventional industries. Many different descriptions of biorefining have been suggested, typically focusing on *fractionation* of the raw material into different components, *diversification* of the mix of products that are produced, *integration* of energy and material flows connecting several processes and *optimization* of the value produced from the raw material. An important approach towards this is the *upgrading of side streams* in the processes – to increase revenue and reduce the amount of waste and waste-handling costs. Several of the biorefining processes are often assumed to be located on one single site – a biorefinery. A parallel is often made to petroleum refineries, which produce a large range of products from the crude oil feedstock.

Examples of descriptions of a biorefinery are:

> "A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum."
>
> (NREL 2009)
>
> "The chemical pulp mill has unique prerequisites for large-scale production of wood-based 'green' polymers and other materials and chemicals, a concept called biorefinery."
>
> (Innventia 2012)
>
> "Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy."
>
> (IEA 3rd task meeting minutes, cited in (Cherubini et al. 2009))
>
> "Full utilization of the incoming biomass and other raw materials for simultaneous and economically optimized production of fibres, chemicals and energy."
>
> (Berntsson et al. 2008)
>
> "Green biorefineries represent complex (to fully integrated) systems of sustainable, environmentally and resource-friendly technologies for the comprehensive (holistic) material and energetic utilization as well as exploitation of biological raw materials in the form of green and residue biomass from a targeted sustainable regional land utilization".
>
> (Soyez et al 1998, cited in (B. Kamm et al. 2006)).

Forest biomass has been used to supply useful services in the form of materials and energy since ancient times and the forest industry of today has developed into a complex industry, which processes forest biomass in to a large range of products. The present interest in biorefineries should be seen in the light of a number of driving forces induced by the challenges to: mitigate climate change by reducing fossil CO_2 emission, reduce the dependence on finite resources, such as petroleum, and – for the traditional forest industry – to adjust to changes in the raw material market and in markets for traditional products.

In this report focus lies on:

> *New, non-conventional processes for refining of forest biomass (i.e. not on conventional heat, CHP, pulp production, etc.), integrated production of multiple products and on the utilization of new forest biomass assortments. Focus is further on value chains containing some steps of decomposition of the raw material on a chemical level, and not on value chains containing only mechanical processing.*

The geographical scope is Sweden and Finland; especially the Botnia-Atlantica (BA) region.

The purpose of the report is to give an overview of development tracks and stakeholders within the biorefinery field. Priority has been on covering a wide scope and providing a good starting point for more detailed studies of interesting biorefinery developments. Hence, the report does not go into detail on developing biorefinery concepts, and does not attempt to draw any final conclusions regarding which developments are most interesting. The information has partly been gathered from web pages and secondary sources, which may not always be up to date. The collected information will be verified in future work of the Forest Refine project, where relevant. Overviews of biorefining technologies and ongoing projects have been assembled in earlier works (Bioref-Integ 2010; Menrad et al. 2009; Rudie 2009; Berntsson et al. 2008; Blue Institute 2009; B. Sandén 2012). The field is, however, rapidly changing, and the present report provides a compilation as well as an update of previous works.

The report gives an overview of the history of forest biomass processing and of the present forest industry. It then moves on to describing current activities within biorefinery technology, research, development and commercialization. However, before proceeding with this, it is useful to take a brief look at other industries that have already developed in a way similar to what is envisaged for the emerging biorefinery industry.

Lessons from other refinery industries

Lynd et al. (2005) studied existing refinery examples in the USA and attempted to draw general conclusions from their development that could be applied to biorefinery development. The two examples studied were oil refining and corn wet milling. Both these industries developed during the 19th century from single product industries – the production of kerosene from crude oil and the production of starch from corn. These industries have since evolved continuously, creating increasingly diverse product portfolios. Key steps in the development of these industries are described in Annex 1.

Based on the assessment of these industries, Lynd et al. (2005) suggests a number of general observations of the development of refinery industries:

- Diversification over time is a key characteristic of refineries: operations shift from those designed to produce single products—e.g. kerosene and starch—to those seeking optimum use and maximum value from each fraction of the feedstock.
- Product slate selection is a function of:
    1) market demand
    2) feedstock availability, composition, and price
    3) available processing equipment and capacity

4) operating costs
5) competitive positioning
6) government regulations

Linear programming algorithms and other sophisticated analytical techniques are used to help optimize refinery product slates.

- Operating flexibility enables refineries to shift outputs over time—on a daily basis for certain petroleum refineries.
- Process improvement invariably makes the cost of raw material the dominant factor in overall refinery economics.

Forest biorefineries

The forest industry of today produces a large range of products from the forest feedstock, for example sawn wood and board products for construction of houses, furniture etc. and paper products for printing, packaging and hygiene, to mention important product groups. Sophisticated methods are used to maximize the value out of tree logs. Examples are pricelists stored in the computer of a forest harvester, to determine the optimal way in which to section each log and x-ray technologies in saw mills used to determine the optimal way to split the log into sawn products. Pulp mills and board manufacturers have made use of side-streams from the saw-mill value chain, such as small-diameter wood from harvest and wood chips and saw dust from saw mills. Waste streams are also to a large extent recovered for internal energy use.

With this background, forest industry as such could be said to already act as a biorefinery. However, the degree of integration between different types of products is in general low, there is a focus on one or a few bulk products and the utilization of side streams is underdeveloped. There has been an increased interest in energy products from the forest industry, for example wood pellet production from saw dust, export of surplus heat and electricity from pulp mills and increased recovery of logging residues and other forest biomass with previously little use. The energy value chain is, however, less developed than sawn wood, pulp and paper value chains. Forest raw materials could also serve as feedstock for a range of chemicals and new materials, but this potential is very little developed. With tightening market conditions, the industry is driven towards a more efficient use of the forest feedstock and increased added value. The issues of climate change and tightening oil supplies has induced a search for forest-based energy and materials that can replace fossil-derived energy and materials. Altogether, these driving forces have led to interest in the development of new products from the forest. Many of these new products are believed to benefit from integrated production in biorefineries, which can also improve energy efficiency by internal energy integration.

Biorefinery platforms, processes and products

Just as there are many definitions of what a biorefinery is, there are several ways of describing biorefineries and classifying them into different types. A common approach is to divide biorefineries into two main groups based on *biochemical processes* and *thermochemical processes,* respectively, but biorefineries could also be classified depending on their feedstock or type of products. Kamm et al. (2006) identify a number of biorefinery types, for example *the lignocellulosic biorefinery,* based on fractionation of lignocellulosic biomass into lignin, hemicellulose and cellulose; *the whole-crop biorefinery,* based on the processing of cereal crops, including both grain and straw fractions; *the green biorefinery,* based on the wet fractionation of green biomass (e.g. grass, lucerne, alfalfa, etc.); the *thermochemical biorefinery,* based on thermal processes, such as gasification or hydrolysis, of the feedstock; and *the two-platform biorefinery,* which combines for example biochemical and thermochemical processes. Also Ree and Annevelink (2007) proposed a similar classification. Cherubini et al. (2009) suggested a general scheme for the classification of biorefineries based on the four features *platforms, products, feedstock* and *processes* (in order of importance).

Platforms are intermediates which link feedstock and final products (Cherubini et al. 2009). There is an analogy in the petrochemical industry, which is based on a number of intermediate products derived from crude oil that are processed into final products.

Products from biorefineries are divided into energy products and material products. Energy products include solid and liquid fuels, energy gases and heat and power. Material products include, for example, plastics, fibers, chemicals, food and feed products.

Feedstock is classified as either dedicated crops or residues, where dedicated crops are grown specifically for use in a biorefinery. This may include, for example, oil- and sugar crops and short rotation energy wood. Residues are feedstock that is produced as a by-product from another process. Examples are logging residues, saw dust, food industry residues etc.

Processes that are applied in a biorefinery may be of many different kinds. Cherubini et al. group processes into *thermochemical*, *biochemical*, *chemical* and *mechanical/physical* processes.

A selection of the most important platforms, products, feedstocks and processes as suggested by Cherubini et al. is presented in Table 1.

Table 1. Biorefinery platforms, products, feedstocks and processes (Cherubini et al. 2009).

	PLATFORMS		**PRODUCTS**		**FEEDSTOCKS**		**PROCESSES**
I	C5 sugars	**I**	**Energy products**	**I**	**Dedicated crops**	**I**	**Thermochemical**
II	C6 sugars	I.1	Biodiesel	I.1	Oil crops	I.1	Combustion
III	Oils	I.2	Bioethanol	I.2	Sugar crops	I.2	Gasification
IV	Biogas	I.3	Biomethane	I.3	Starch crops	I.3	Hydrothermal upgrading
V	Syngas	I.4	Synthetic biofuels	I.4	Lignocellulosic crops	I.4	Pyrolysis
VI	Hydrogen	I.5	Electricity and heat	I.5	Grasses	I.5	Supercritical
VII	Organic juice			I.6	Marine biomass		
VIII	Pyrolytic liquid	**II**	**Material products**			**II**	**Biochemical**
IX	Lignin	II.1	Food	**II**	**Residues**	II.1	Fermentation
X	Electricity and heat	II.2	Animal feed	II.1	Lignocellulosic residues	II.2	Anaerobic digestion
		II.3	Fertilizer	II.2	Oil based residues	II.3	Aerobic conversion
		II.4	Glycerine	II.3	Organic residues & others	II.4	Enzymatic processes
		II.5	Biomaterials				
		II.6	Chemicals and building blocks			**III**	**Chemical processes**
		II.7	Polymers and resins			III.1	Catalytic processes
		II.8	Biohydrogen			III.2	Pulping
						III.3	Esterification
						III.4	Hydrogenation
						III.5	Hydrolysis
						III.6	Methanisation
						III.7	Steam reforming
						III.8	Water electrolysis
						III.9	Water gas shift
						IV	**Mechanical/physical**
						IV.1	Extraction
						IV.2	Fibre separation
						IV.3	Mechanical fractionation
						IV.4	Pressing / disruption
						IV.5	Pretreatment
						IV.6	Separation

A key issue in forest-based biorefineries is how to separate the wood into its constituents. Therefore, the key separation process – such as gasification, hydrolysis or sulphate pulping – may be an important characteristic of a forest biorefinery. Another way to describe biorefineries, which may increase the understanding of their development, is to classify them by their key business, such that the key business of pulp-mill based biorefineries may be pulp or paper production, while another biorefinery may have liquid biofuel production as their key business.

An analogy could be made to a petroleum refinery with motor fuel production as their key business and distillation as the key separation process.

Traditional and future pathways

Some of the main traditional and expected future pathways from forest resource to final products are illustrated in Figure 1. The existing forest industry of today clearly represents a complex industry where different parts of the raw material and process by-products are refined into value-added products. In this sense, the industry as a whole exhibits the characteristics of a biorefinery. It is, however, noticeable that it is mainly the mechanical properties of the wood that is exploited. What is envisaged in the new pathways is that the raw material should also be utilised for chemical products, and more advanced energy products, whereas today the energy applications are mainly focused on recovery of the thermal energy by means of combustion.

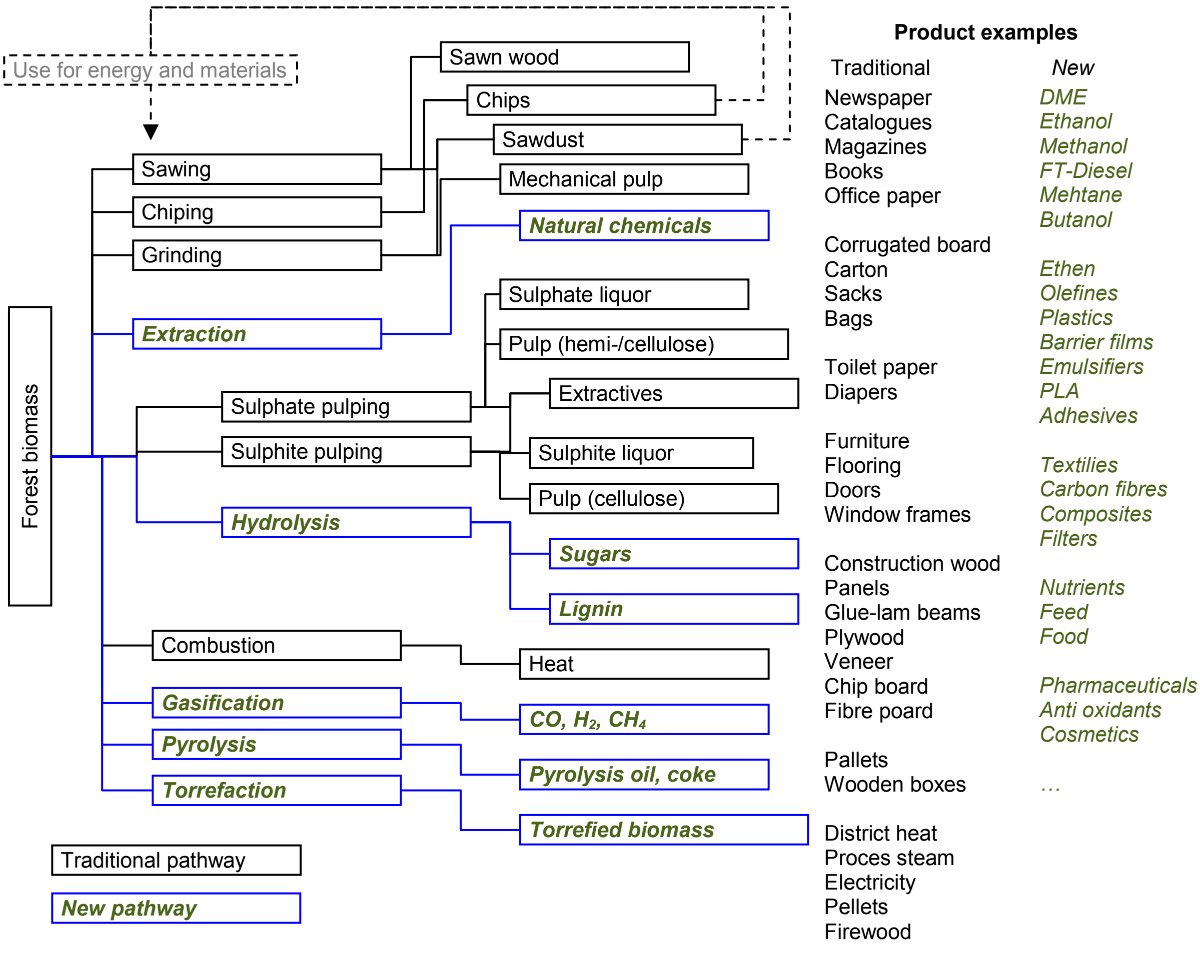

Figure 1. Some of the main traditional and new pathways from forest biomass resources to end products

Historical development

The forest has always been an important resource in Sweden and Finland, for local use and – increasingly – for export products. This is especially true for the BA region. Here, wood tar was for long times an important export product and the area was central in the booming saw-mill industry of the 19th century – and later on the expansion of the pulp industry. The development of the Finnish and Swedish forest industries share many common features. The two nations also share a common history, as they were unified in one country for 600 years. The following sections review the forest industry history with a focus on Sweden, followed by some remarks on developments specific to Finland.

When seeking explanatory patterns for historical development, different conclusions might be reached depending on the perspective taken. In this report the interpretations of the historical events are mainly based on (Jörnmark 2004).

Sweden

The development has been subject to a constant interplay of changing market conditions, technical and infrastructural development and political regulation. Prior to the forest industry expansion in Sweden, the metallurgical industry – primarily in the southern half of the country – was a large user of charcoal produced from wood. However, in the course of the industrialization of Europe, the price of charcoal relative to hard coal was constantly increasing. One reason for this was the ample supply of hard coal in Europe, but, maybe equally important, the emerging pulp industry had a high ability to pay for the small-diameter wood and saw mill waste that was being used for charcoal production; which pushed the price of charcoal upwards. The Swedish metallurgical industry also faced a transportation disadvantage towards the industries in continental Europe. Part of their solution was to move towards an increased degree of specialization. This became the foundation of the, for Sweden, very important mechanical engineering industry (Jörnmark 2004).

The development of the metallurgical industry is one example of a transformation induced by changing energy markets, technical development and competition between industries. In the following, a brief description is made of the historic development of the Swedish forest industry.

Charcoal, wood tar, potash

Expansion of maritime transport in the 18th century increased the demand for tar, which was used to impregnate wood, ropes etc. used for ships, especially in countries such as England and the Netherlands (Västerbottens Museum n.d.; Åström 1988). Wood tar became an important export product for Sweden and Finland, where it was produced from pine stumps and fatwood ("tjärved"). In the 17th century, tar was third in importance of the export products, after iron and copper (Åström 1988). Timber and sawn wood products took over as the most important export products from the forest in the middle of the 19th century (Åström 1988).

Charcoal was early used as domestic fuel and for metal production and crafting. Increasing iron production in the 18th century demanded large amounts of charcoal. Later on, also, the use of steam engines that used charcoal for fuel expanded (Andersson & E. Sandén 2007). Both tar and charcoal were produced through pyrolysis of wood, initially in primitive charcoal kilns and tar pits and later on under industrial conditions. For example, the Swedish chemical company Perstorp has its roots in a tar- and charcoal producing industry (See *Example:Perstorp)*.

A third product which early was economically important was potash. Potash was produced from birch ash and it was used in the production of glass and soap. In Västerbotten, the production was largest in the first half of the 19th century, but then diminished, partly due to a shortage of birch trees (Västerbottens Museum n.d.).

Example: Perstorp
The origin of the chemicals manufacturer Perstorp, in the south of Sweden, was a company established in the 1880's with the intention to produce acetic acid, tar, charcoal and wood alcohol. The products were successively developed into new product lines. In 1907, formalin production started and formed the basis of a long line of products. Formalin based products are still produced by Perstorp, but now with natural gas as the feedstock basis (Perstorp 2012).

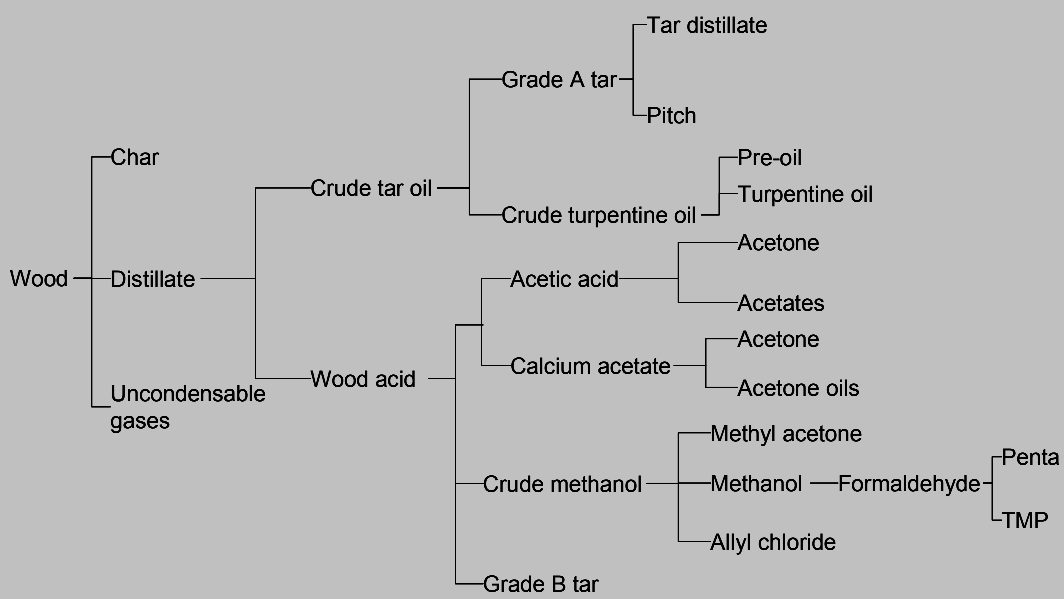

Figure 2. Historic production lines of Perstorp. Redrawn and translated from (Rex 2012).

Sawmills and wood products

The Swedish saw-mill industry grew during the first half of the 19th century, and was booming in the 1840's and 50's. Between 1842 and 1860, the Swedish wood products export increased by approximately four times (Jörnmark 2004). There were several reasons for this growth. Among those were: technical development, international demand from countries leading the industrialization process and liberalization of international trade as well as national legal frameworks. The British import duties on wood were lowered in 1842, and eventually removed in 1866 (Jörnmark 2004). Liberalization of the national legal framework that occurred in Sweden around the same time made it easier to acquire and trade in forest raw material. Previously, the establishment of sawmills had been a cumbersome process, for example requiring-far reaching consequential analyses of the impact of a saw mill establishment on the wood supply situation of existing iron industries (Jörnmark 2004). The liberalization made it possible and fruitful for foreign entrepreneurs – with good connections with the export markets – to establish businesses in Sweden. Bünsow, Braathen, Astrup, Storjohann, Dickson and Bing were names of central importance for the development in the forest industry (Jörnmark 2004). These business were often export oriented, while existing small sawmills were connected to iron industry and the local market.

The export of saw-mill products was dependent on shipping and thus on coastal harbors. Also inland, the waterways were the only feasible means of transportation for the large amounts of wood and wood products. With the implementation of steam engines, the saw mills were no longer dependent on hydropower and could be located away from the inland waterfalls. It was natural to situate them at the river mouths at the coast. Hence, logs could be transported on the rivers to the industry and the finished products could be loaded onto seagoing ships at the industry. The concentration of forest industries in northern Sweden towards the coast is a structure that remains today.

Pulp and paper industry

The pulp industry derived from the saw-mill industry. Most pulp mills were established to increase the value of saw-mill by-products and of small-diameter wood recovered in the harvest of timber for saw mills (Valeur 2003). The invention of the paper machine increased the pulp demand and the pulp industry grew in importance in comparison to the saw mills, with the growing pulp and paper market. During the 20th century, the global paper consumption grew from approximately 1.5 million tonne per year to 350 million tonne per year (Jerkeman 2010). The first growth period for the Swedish pulp industry occurred mainly in the southern and western parts of Sweden and was based on mechanical wood pulp production. During the 1890s, the chemical pulping technology emerged and was to a large extent located to the northern parts of Sweden (Blomström & Kokko 2002).

The rapid expansion of the sawmill industry in northern Sweden was slowing down during the 1890's, as a consequence of increasing competition for the raw material and a turn towards more protectionism and regulation of the previously liberalized legislation (Jörnmark 2004; Blomström & Kokko 2002). The expansion of the pulp industry compensated for the stagnation in the saw mill industry, and innovations within paper making, bleaching and cellulose silk production followed as a consequence (Jörnmark 2004). The increased competition for the raw material and the development towards further refining of the raw material in paper production also provoked vertical integration in the forest industry. This trend, and the important economies of scale in cellulose production, led to fusions of forest industry companies into larger units, which demanded larger forest resources to supply the pulp mills. The harness of hydropower for electricity took off in the early 20th century, which had a large influence on the industry development, and conglomeration involving forest industry, electric power industry and chemical industry became common. The industry became very capital intensive, and dependent on banks for their financing. In bad times, such as in the 1920s, this also led to that large companies were taken over by the banks (Jörnmark 2004).

During the Second World War, the export market largely disappeared and the pulp industry had to severely cut down its pulp production. For example, SCA shifted production from pulp towards delivery of wood for wood-gas driven vehicles and production of charcoal, wood tar, turpentine and pulp for cellulose ethanol production (SCA 2009).

The decades following the Second World War saw a concentration of pulp and paper production to fewer but larger units. The industry was internationalized in the 1980s and 1990s through acquisitions of foreign paper and paper product producers (SCA 2009; Blomström & Kokko 2002).

The structure of the pulp industry has continued to shift towards fewer but larger mills. At the beginning of the 20th century, there were 70 mills producing groundwood mechanical pulp and 30 producing chemical pulp – all small mills with an annual production of less than 5000 tonnes (Jerkeman 2010). In the early 1900s, several mills were built for the export market. Sulphate mills were constructed to exploit pine wood, which was unsuitable for both mechanical pulping and sulphite pulping. The total number of pulp mills peaked at 130 mills in the 1930s. Two large sulphate pulp mills were built in the 1950s, and since then up till today only two more mills were built, while many smaller mills have had to shut down (Jerkeman 2010). Meanwhile, the amount of pulp and paper produced has increased (Table 2).

Table 2. Structural development in Swedish pulp and paper industry (Skogsindustrierna 2012)

	1960	1970	1980	2000	2011
Pulp					
Number of mills	127	98	72	51	41
Total capacity, Mt	5.6	8.9	10.5	11.1	13.3
Capacity/mill, kt	45	90	145	218	324
Paper					
Number of mills	76	68	62	52	39
Total capacity, Mt	2.3	4.8	7.2	9.1	12.2
Capacity/mill, kt	30	70	115	175	315

Mechanical pulp, sulphite pulp and sulphate pulp

Wood pulp production over the past century has been based on either of three main groups of pulping processes: Mechanical pulping, sulphite pulping and sulphate pulping. The three processes give different quality pulps, have different raw material requirements and generate different by-products. They therefore have different possibilities for biorefinery development. In the following, a brief description of their development is given, based on (von Troil 2010). Current developments in pulp-mill based biorefineries are discussed later in this report.

The early pulp mills produced groundwood mechanical pulp. The wood was simply grinded into fibers that could be used for paper making. Sulphite and sulphate chemical pulping were invented in the 19th century and increased in use during the beginning of the 1900's. In mechanical pulping, most of the wood is maintained in the pulp, while both sulphite and sulphate pulping serves the purpose to remove the lignin part of the wood from the cellulose fibers. The sulphite process also removes most of the hemicellulose and produces a purer cellulose pulp. The sulphate pulp, on the other hand, is stronger, and it was until the middle of the 20th century mainly used for packaging applications, such as sack paper.

Hemicelluloses dissolved in the sulphite process was used for ethanol production before world war II – some of it also for drinking purposes – but during the war, the ethanol chemistry was developed to substitute for import fuels and chemicals (see *Example: Domsjö*). With the return of cheap petroleum-based products after the war, the need for ethanol-based chemicals diminished. Vanillin and xylitol are other substances that have been produced from sulphite liquors. The lignin recovered as lignosulphonates have found uses as for example dispersants.

By-products from the sulphate process are of a different nature. Turpentines, tall oil and the lignin-rich black liquor have mainly been used for internal energy use. Recently, there has been an increased interest in recovering these by-product streams for higher-value purposes.

With the invention of chlorine dioxide bleaching, the sulphate pulp could be bleached well enough for graphic paper applications, and an important disadvantage towards sulphite pulp was overcome. The sulphate process had two key advantages: higher pulp strength and larger raw material flexibility, compared to mechanical pulping and sulphite pulping. Importantly, sulphate pulping could utilize pine wood, which caused problems in mechanical pulping and sulphite pulping, due to the extractives in the wood. The higher strength of the sulphate pulp allowed for higher speeds in the paper production and hence increased productivity of the paper machines. Also, technologies for recovery of pulping chemicals and the utilization of pulping liquors for energy purposes was developed earlier for the sulphate process than for the sulphite process.

All together, these factors resulted in that the sulphite process was squeezed between the sulphate process with high pulp strength and raw material flexibility and the mechanical pulp processes with high pulp yields. The more versatile use of by-products in the sulphite pulp mills was not enough to make it competitive.

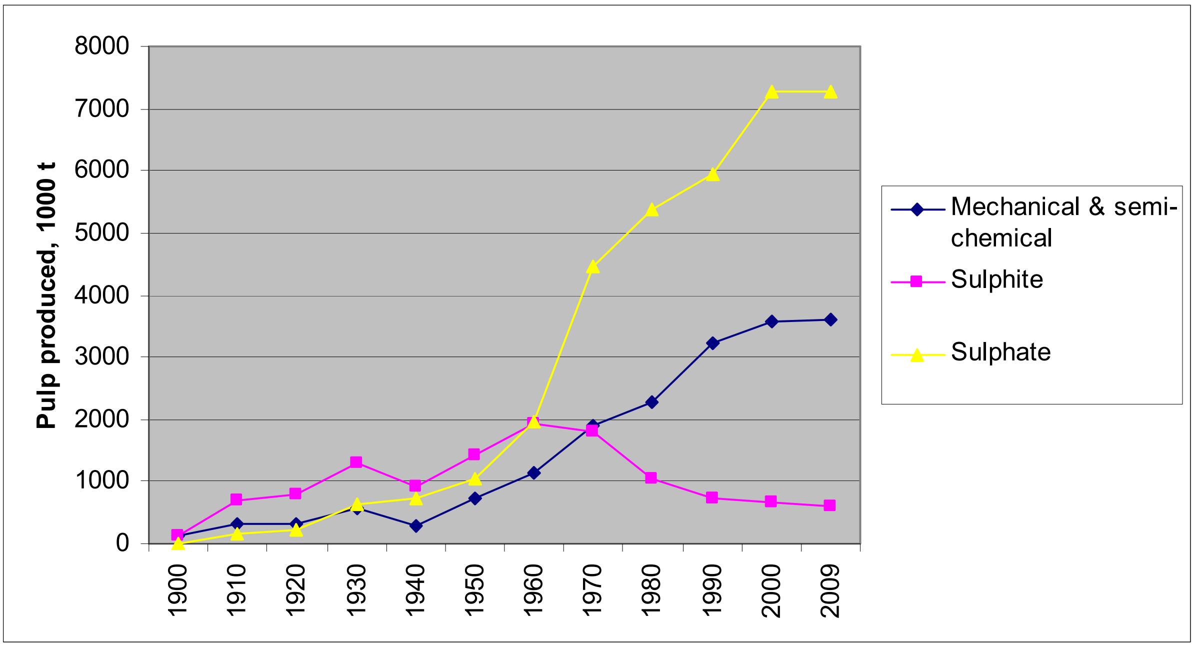

Figure 3. Production of mechanical pulp, sulphite pulp and sulphate pulp in Sweden 1900-2009 (von Troil 2010).

Example: Domsjö

The Domsjö sulphite mill was taken into operation in 1903. In 1930 the mill started to produce dissolving cellulose for use in viscose products. A chlorine production facility was taken into operation in 1936, and an ethanol production unit in 1940. The mill developed into a chemical production industry based on wood raw material during world war II.

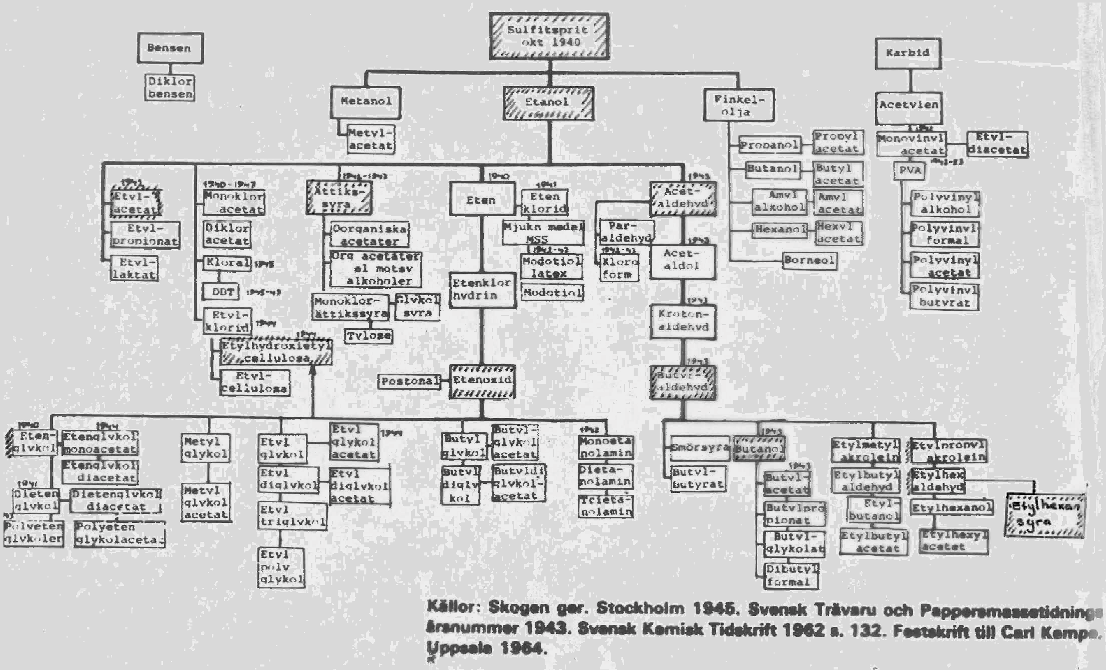

Figure 4 Schematic view of the organic chemistry industry of Mo and Domsjö during world war II (In Swedish).

After the war, the chemicals production was closed down while pulp production continued. Since year 2000, the mill has again developed towards a biorefinery producing several products. Specialty cellulose, ethanol and lignosulphonate are the key products.

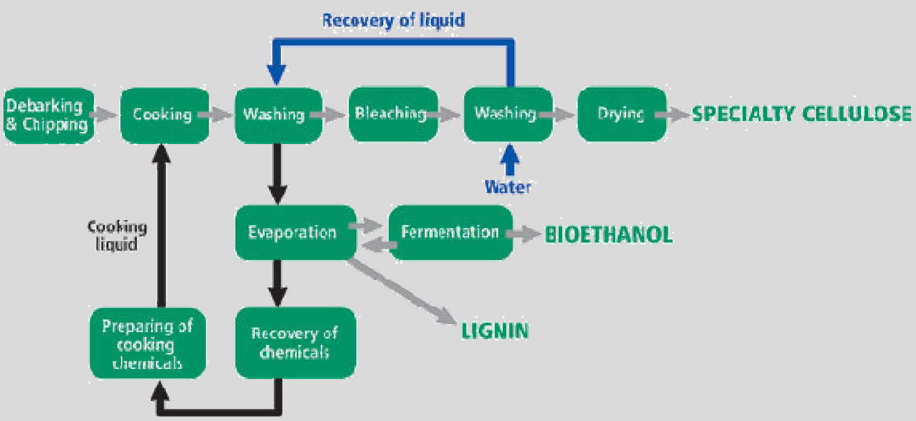

Figure 5 The Domsjö process today (Domsjö 2012a)

Finland

As in Sweden, wood has been used in Finland for several purposes, such as firewood, charcoal and wood tar. Also in Finland, tar was an important export product before the development of the saw-mill industry. In the 1830's, tar, which had dominated the Finnish export trade for a long time, lost its leading position to saw-mill products. The Finnish saw-mill industry started to grow rapidly in the middle of the 19th century and made a breakthrough in the 1870's. The reason behind the fast growth was that steam saws were allowed and sawing quotas were removed. In addition, at about the same time British removed the timber duties. In Sweden, timber production and export evolved even faster, and in 1860 the exportation was three times larger compared to Finland. Although the saw-mill industry existed also in inland, it was mainly concentrated in the coast because the market of timber products was overseas in Western Europe (Kuisma 2006). In 1927, there were more than 600 sawmills in Finland, providing employment for 45 000 people. Until the 1930's, the saw-mill industry was economically the most important sector in Finland. At that time pulp and paper industry became the largest exporter in Finland. (Metsäteollisuus n.d.)

As well as the saw-mill industry, the Finnish pulp industry, based at first on mechanical wood pulp production, started to develop rapidly in the latter half of the 19th century. Since the introduction of wood pulp in the production of paper, several groundwood pulp mills and paper and board mills were built in Finland in following years (Leppänen 2004). The paper mills at that time utilized rags as raw material, and later together with mechanical wood pulp. The first chemical pulp mill in Finland was founded in 1876. Chemical pulp mills provided raw material, cellulose fibers, for paper making to replace rags. Before the World War I started, Finnish wood processing industry comprised some 600 sawmills, three plywood mills, 17 pulp mills and 25 paper mills (Metsäteollisuus n.d.).

Finland was part of Russia during a very expansive period for the forest industry, starting with the saw mill industry expansion in the middle of the 19th century and followed by the pulp and paper industry towards the end of the 19th and beginning of the 20th century. Since Russia had large saw-mill industry, timber products were exported to Western Europe. However, at this time, Russia was the main market of the Finnish paper industry, and pulp and paper were almost entirely delivered to Russia. Being part of Russia, the Finnish industry did not have to pay import tolls. With the independence of Finland, the civil war and the closure of Russia after the revolution in 1917-18, conditions changed drastically for the Finnish forest industry, and one of their most important markets disappeared almost overnight (Levlin 2011).

After this event, the Finnish pulp and paper industries formed joint sales organizations: Finncell, Finnpapp and Finnboard, which helped the industry to establish on new markets – mainly other European countries – in a way that would have been difficult for many smaller companies on their own. The pulp and paper production could therefore grow rapidly. Today, Europe constitutes the main export market for the Finnish pulp and paper products (Levlin 2011). The joint sales organizations disappeared after Finland had entered the European Union.

In recent years, increased competition and weakening demand for printing paper has put pressure on the European pulp and paper industry. Also the Finnish industry has been much affected, especially since it has historically had a strong focus on newsprint and other printing paper products. One reason for this focus in Finland has been that the Finnish spruce wood was considered a very suitable feedstock for printing paper production (Levlin 2011).

Present use of forest biomass

The total standing stemwood volume of Swedish and Finnish forests is around 3200 and 2284 million m^3 (Mm^3), respectively. The annual growth is about 120 Mm^3 in Sweden and 104 Mm^3 in Finland. In average, the volume of all felled stems (including unharvested stems) was 90 Mm^3 in Sweden and 63 Mm^3 in Finland. Hence, the volume of standing stemwood increased by around 30 Mm^3 and 41 Mm^3, as an annual average, in Sweden and Finland, respectively. Almost all of the harvested roundwood is used domestically - only 1 Mm^3 is exported.

The present raw material supply system is built around the supply and demand for saw logs and pulp wood. Logging residues have increasingly been recovered for energy use. There is an extensive flow of by-products between industries where, mainly, saw mill by-products are used by pulp mills, pellets industries and heating plants. Pulp mill by-products are mainly recovered for internal energy use. The main flows of stemwood in 2010 in Finland and Sweden are illustrated in Figure 6.

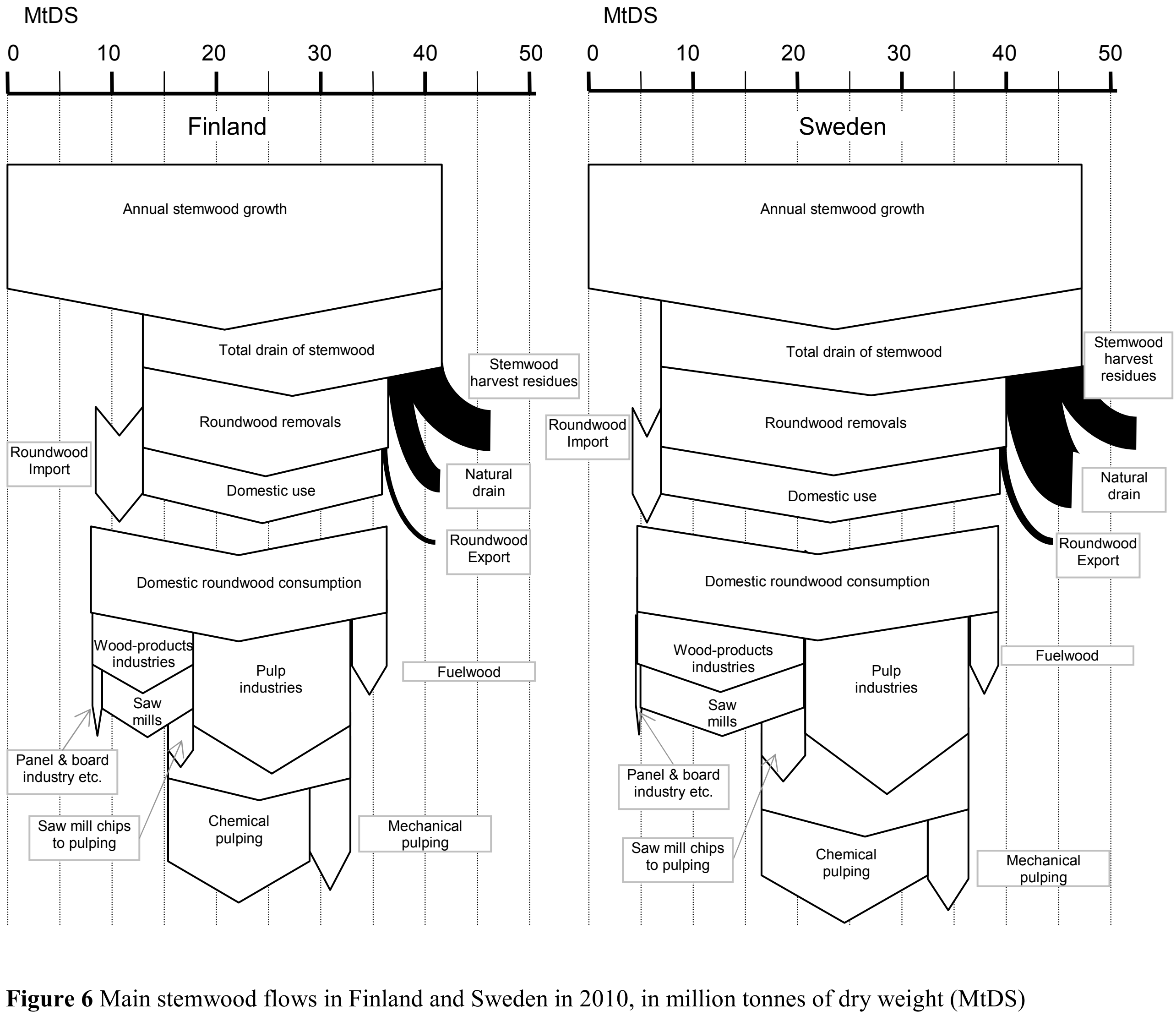

Figure 6 Main stemwood flows in Finland and Sweden in 2010, in million tonnes of dry weight (MtDS) including bark (Loman 2011; Wigrup 2012; Ylitalo 2011). The figure is based on aggregated forest statistics data and typical conversion factors for various volume units to dry mass units, and gives only an approximate magnitude of the flows.

Bioenergy accounts for a large share of the energy supply in Finland and Sweden (Tables 3 and 4, Figure 7). Internal use of by-products in pulp mills constitutes the largest part of the bioenergy use. The Swedish electricity generation is mainly based on nuclear power and hydropower. In Finland, these energy sources accounts for a somewhat smaller share, an the heat and power sector also uses significant amounts of fossil fuels. This difference may imply somewhat different interests in large-scale electricity production from biomass in Finland and Sweden. In Sweden, however, the future of nuclear power is not clear, while, presently Finland are actively seeking to increase the nuclear power capacity.

In 2010, 16 and 19 Mm^3 of wood, consisting mainly of bark and forest chips, was consumed in heat and power plants in Finland and Sweden, respectively. Additionally, 6.7 Mm^3 of wood was consumed by households, mainly as firewood, both in Sweden and in Finland (Ylitalo 2011; Finnish Forest Research Institute 2010; Loman 2011).

Table 3. Energy balance table of Sweden in 2010 (Eurostat 2012)

Sweden 2010 PJ	Coal etc	Natural gas	Oil etc	Nuclear heat	Peat	Bio-mass	Wind etc.	Hydro energy	Heat	Elect-ricity	**Total**
Primary supply etc	0	0	0	625	10	477	13	239	0	0	**1385**
Imports	103	55	1180	0	5	0	0	0	0	54	**1396**
Exports and bunkers	1	0	615	0	0	0	0	0	0	46	**663**
Gross inland supply	**90**	**55**	**608**	**625**	**15**	**477**	**13**	**239**	**0**	**7**	**2150**
Energy sector input	82	32	934	625	15	222	0	0	0	6	**1937**
Energy sector net output	34	0	868	0	0	0	-13	-239	224	509	**1383**
Distribution losses	0	0	3	0	0	0	0	0	9	38	**50**
Final domestic use	**41**	**23**	**539**	**0**	**0**	**255**	**0**	**0**	**215**	**472**	**1546**
Non-energy use	1	0	83	0	0	0	0	0	0	0	**84**
Industry	50	13	55	0	0	194	0	0	19	196	**527**
Transport	0	1	336	0	0	17	0	0	0	9	**362**
Households	0	3	3	0	0	29	0	0	135	146	**316**
Services	0	1	26	0	0	2	0	0	61	118	**207**
Agriculture/Forestry/Fishing	0	1	9	0	0	13	0	0	0	5	**28**

Table 4. Energy balance table of Finland in 2010 (Eurostat 2012)

Finland 2010 PJ	Coal etc	Natural gas	Oil etc	Nuclear heat	Peat	Bio-mass	Wind etc.	Hydro energy	Heat	Elect-ricity	**Total**
Primary supply etc	0	0	5	246	76	330	1	47	0	0	**711**
Imports	167	161	687	0	0	5	0	0	0	57	**1076**
Exports and bunkers	0	0	313	0	0	3	0	0	0	19	**335**
Gross inland supply	**193**	**161**	**430**	**246**	**95**	**332**	**1**	**47**	**0**	**38**	**1548**
Energy sector input	190	104	638	246	84	136	0	0	0	1	**1404**
Energy sector net output	24	-12	597	0	0	-1	-1	-47	208	273	**1041**
Distribution losses	0	0	2	0	0	0	0	0	12	10	**24**
Final domestic use	**26**	**44**	**387**	**0**	**11**	**195**	**0**	**0**	**195**	**300**	**1161**
Non-energy use	0	12	54	0	0	0	0	0	0	0	**66**
Industry	26	28	73	0	10	125	0	0	78	145	**486**
Transport	0	1	199	0	0	6	0	0	0	3	**208**
Households	0	2	24	0	1	60	0	0	71	85	**242**
Services	0	1	13	0	0	4	0	0	0	64	**82**
Agriculture/Forestry/Fishing	0	0	25	0	1	6	0	0	0	3	**36**

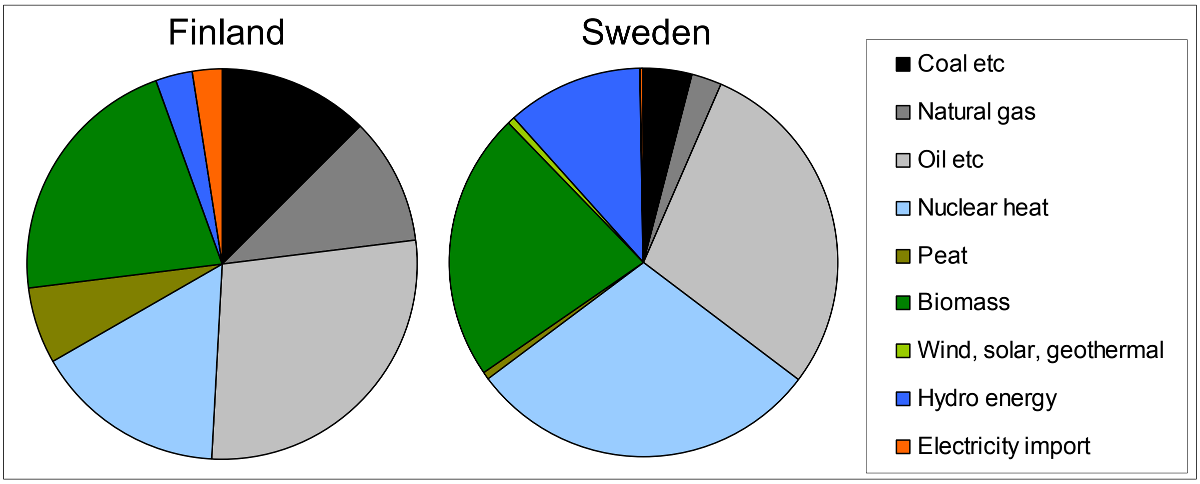

Figure 7 Composition of the gross inland energy supply in Finland and Sweden in 2010 (Eurostat 2012)

Current status of biorefinery development

This section reviews existing and planned activities within the biorefinery field in Finland and Sweden. Given the wide range of activities that, in some way, has an influence on the biorefinery development, it is not possible to give a complete picture of the field. Nor has the ambition been to rank which activities and organizations are more important than others, but rather to give a broad overview of main development paths and to give a diverse set of examples of activities and organizations. The information has partly been gathered from web pages and secondary sources, which may not always be up to date, and it will be verified in forthcoming work of the Forest Refine project.

First a general overview is given of research, cluster and network activities. Next, activities within specific biorefinery development paths are described.

Research and clusters

Over the recent years there have been many large research projects targeting, directly or indirectly, the biorefinery area. Key players include **universities** and **research institutes**, but also **consultants** and **industry companies**. Some important Swedish research funders are the **Swedish Energy Agency**, **the Swedish Governmental Agency for Innovation Systems (VINNOVA), the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS)** and **the Foundation for Strategic Environmental Research (MISTRA).**

Some important Finnish research funders are: **TEKES – Finnish Funding Agency for Technology and Innovation.** Tekes is the main public funding organization for research, development and innovation in Finland. **The Academy of Finland** provides funding for scientific research of the highest quality. Other important funding agencies are **The Centres for Economic Development, Transport and the Environment (ELY).** Many of the Swedish and Finnish research activities are also part of EU-funded projects.

Selected research projects related to biorefineries are listed in Annex 3.

NER300
NER300 is an EU instrument for financing of commercial demonstration projects that aim at the environmentally safe capture and geological storage of CO_2, as well as demonstration projects of innovative renewable energy technologies (European Commission 2010). It is funded by the sale of 300 million greenhouse gas emission allowances (the New Entrants Reserve). The program is split into (at least) two calls. Applications for the first call has been prioritized and final decisions are expected by the end of 2012 (European Commission 2012).

See Annex 2 for a list of projects that are applying for NER300 support.

Clusters, networks and centers

The need for clustering as a means to improve co-operation, synchronize efforts and attract funding has resulted in a number of centers and networks being formed.

Sweden

Some Swedish centers, with a focus on the northern part of Sweden, are:

BioFuel Region is a collaborative project between the public sector, the private sector and universities in the Swedish counties of Västerbotten and Västernorrland. Its vision is to become a world-leader in the transition to biofuels and products based on renewable raw materials by mobilising, involving and activating the positive forces for development that exist in the region.

The Biorefinery of the Future is a cluster for biorefinery development from wood raw material and energy crops. The cluster has the coastal region of northern Sweden as its geographical focus and comprises industry, academic institutions and public organizations. Processum Biorefinery Initiative is the host of the Biorefinery of the Future.

NumberOne is a forest industry network centered in Sundsvall with its geographical focus in a region stretching over parts of the Västernorrland and Gävleborg counties. It comprises approximately 80 companies and organisations related to forest industry.

Fibre science and communication network (FSCN) is a multi-disciplinary research centre organizing researchers at Mid-Sweden University. The aim is to improve the profitability of today's paper industry, and to find new ways to use the Forest as a Resource. This involves the refining of materials that are extracted from the forest industry material flows and the development of new ways to use wood fibers, paper and board, for example in three-dimensional packaging structures.

Solander Science Park is a centre for research, innovation and entrepreneurship located in Piteå. It is the result of a local development work initiated by Smurfit Kappa, SCA Munksund, ETC (Energy Technology Centre), the Municipality of Piteå and IS Pite. During 2008-2013, there is an ongoing project to develop the business and establish Solander Science Park, nationally and internationally as a centre for biorefinery technology.

Swedish Gasification Centre (SFC) is a research centre where a number of academic stakeholders cooperate with the industry and has a total budget over 10 years of 540 million. Its purpose is to create a national skills base for research, development and postgraduate education in the biomass gasification technology and related fields.

Swedish Knowledge Centre for Renewable Transportation Fuels (f3) – a nationwide centre, which through cooperation and a systems approach will contribute to the development of sustainable fossil free fuels for transportation.

Wallenberg Wood Science Centre is a joint research centre at Royal Institute of Technology (KTH) and Chalmers which aims to build a material research program that can develop new material products using the Swedish forests.

Finland

Finnish Bioeconomy Cluster FIBIC Oy (previously Forestcluster Ltd) is one of the six Strategic Centres for science, technology and innovation in Finland (SHOK). FIBIC has evolved from Forestcluster Ltd founded in 2007 by key forest cluster companies and main research institutes and universities in Finland. As a result of the change, the research activities are expanding from the research focused on forest industry also towards other areas of the bio-based economy (FIBIC n.d.).

CLEEN Ltd (Cluster for Energy and Environment) is also part of SHOK's. CLEEN, founded in 2008 by major companies in the field of energy and environment and most relevant research organizations, coordinates industry-driven energy and environmental research in the field of energy and environment (CLEEN n.d.).

Benet Bioenergy Network administrated by the Benet Ltd consists of 6 independent expert organizations as members. Founded in 1997, the Benet network has operated for over 10 years and implemented over 50 international joint projects.

Benet Ltd is a Finnish expert company who markets and implements bioenergy expert services. The Benet aims to increase the use of environmentally and economically sound bioenergy use by creating preconditions for bioenergy use, and by developing, consulting, implementing and coordinating bioenergy related projects (Benet n.d.).

The next cluster programmes are part of a national Centre of Expertise programme (OSKE):

Forest Industry Future competence cluster aims to find new solutions for the industry and especially to support the growth of the small and medium-sized firms and to promote the reformation of the field. These goals are pursued by developing new technologies, operating models, products, and services. The premise for development is versatile innovation, which combines both research and technology and business knowledge. The operation of the competence cluster is heavily focused on national and global networking.

The operation of the competence cluster is coordinated by Lappeenranta Innovation Oy, and the other six Centres of expertise participating in its implementation are: Jyväskylä Region, Southeast Finland, Kokkola Region, Mikkeli Region, Measurepolis-Kajaani measurement technology and North Karelia (FIF n.d.).

Energy Technology cluster focuses on industrial enterprises that manufacture machinery and devices used in energy production, consumption and distribution, as well as on service providers in the field of energy technology.

The cluster programme develops strong industry-centered research, development, innovation and education environments.

The Centres of Expertise that are part of Energy Technology Cluster are Western Finland Centre of Expertise, Jyväskylä Region Centre of Expertise, North Karelia Centre of Expertise, Satakunta Centre of Expertise, Tampere Region of Expertise, Southeast Finland Centre of Expertise and Varkaus Region Centre of Expertise (OSKE n.d.).

Development and demonstration within specific areas

The following sections list developments within certain key areas. The activities have been grouped into the categories hydrolysis & ethanol, gasification, pyrolysis & torrefaction, pulp mill based and other research and development projects (Figure 8).

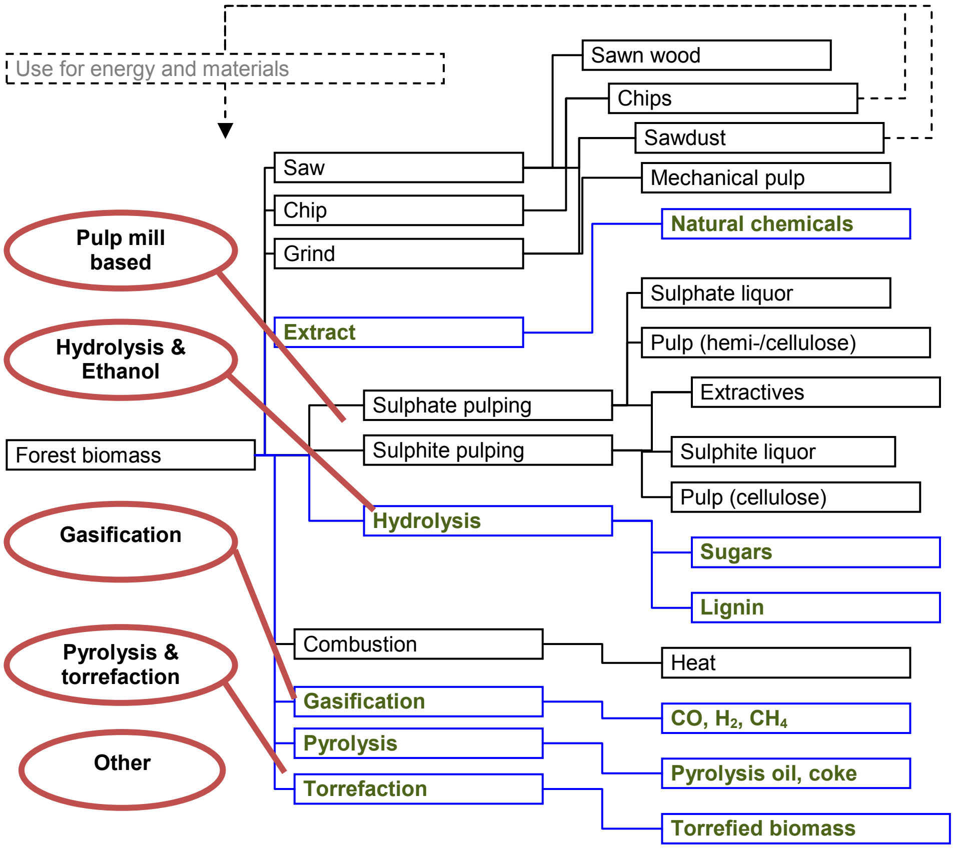

Figure 8. Biorefinery activity categories.

Cellulose hydrolysis and ethanol production

Sweden

There have been extensive activities in Sweden related to the conversion of woody biomass into fermentable sugars. These activities have mainly been motivated with the aim of producing ethanol for use as motor fuel. The knowledge gained could, however, be applied in the production of other sugar-based fuels or chemicals. The Swedish Energy Agency has been important in funding ethanol research through its ethanol programs, running since 1993 and presently being continued within the program “Ethanol processes” (Etanolprocesser) in 2011-2015 (Energimyndigheten 2011).

Pre-treatment of the feedstock and the subsequent hydrolysis of cellulose into monomer sugars are key parts of the process. Enzymatic methods, treatment with acids or a combination of these are the main hydrolysis technologies pursued in current development projects. Other alternatives exist, such as organosolve processes or treatment with ionic liquids.

SEKAB is a Swedish company active within ethanol fuels and chemicals. SEKAB is owned by a regional ownership consortium comprising Övik Energy, Umeå Energy, Skellefteå Power, Länsförsäkringar in Västerbotten, OK Economic Association and EcoDevelopment (SEKAB 2012). Through SEKAB Biofuels & Chemicals imports, produces, refines and sells ethanol as fuel (for low-level blending and as neat ethanol fuel). At the plant in Örnsköldsvik, ethanol-derived chemicals are produced, including acetaldehyde, ethyl acetate, ethanol 99% and acetic acid (SEKAB 2012).

SEKAB E Technology works with development of ethanol production from cellulose, including pre-treatment, hydrolysis, fermentation and distillation (SEKAB 2012). Biogas and lignin are by-products from the ethanol production.

SEKAB E-technology has been responsible for operating the **Ethanol Pilot Plant** – a 200 m^3/year plant for development and demonstration of cellulosic ethanol production - located at the Domsjö area in Örnsköldsvik. The "Ethanol Pilot" was inaugurated in 2004 and has been funded by money from the Swedish Energy Agency, the EU and SEKAB. It is owned by universities of Umeå and Luleå together with SEKAB, through Etanolpiloten i Sverige AB (EPAB). As SEKAB E-technology is now ending its most intensive development work in the Ethanol Pilot, new forms for its continued operation are presently being investigated.

NBE Sweden was founded in 2006 with the purpose to develop technology for conversion of cellulose raw materials to ethanol, electricity and solid fuels. It is owned by NBE Co. Ltd. (Beijing, China), Dragon Power Co. (Beijing, China), Härjedalens municipality (Sveg) and HMAB, Härjedalens Miljöbränsle AB (Sveg) (NBE Sweden n.d.). NBE Sweden has operated a development plant for pre-treatment and hydrolysis in Sveg. The plant is based on a batch process with 500 kg feedstock capacity per batch, designed for up to five batches per day. The development plant does not include fermentation of the sugars to ethanol and it has now been mothballed. NBE Sweden is seeking to finance the construction of a larger-capacity plant at the same location. Necessary environmental permits have been obtained. The lager-scale plant would be integrated with an existing pellets- and briquettes factory and a combined heat and power plant. Greenhouses would be constructed to make use of low-grade heat and carbon dioxide (NBE Sweden 2009).

Finland

St1 is a Finnish energy company, which produces mostly ethanol and distributes it through St1 and Shell stations in Finland, Sweden and Norway. In terms of production, the company has developed various patented products such as Etanolix and Bionolix. There are total of 7 ethanol production units and one dehydration unit. In construction, St1 has one biogas unit, as well. The total production of ethanol is 15 million litre/year (Aho 2012; St1 2012, sited in (Raghu 2012)). As a feedstock, St1 uses waste and by-products from food industries. Small bioethanol producing plants are established near to the source of feedstock in order to minimize transportation cost. 85% of ethanol produced is sent to dehydration unit that dewaters it to 99.8% ethanol, which is ready for blending with petrol (St1 2012, cited in (Raghu 2012)). A fuel brand called RE85 is a product from St1, which is being sold in Finland through tens of St1 stations. RE85 is suitable for flexfuel cars and contains 80-85% bioethanol (RE85 n.d.).

Chempolis is a Finnish technology company that provides various solutions in sustainable production of various chemicals and fuels. Its expertise has developed two major process technologies called Formicofib™ and Formicobio™. The former is a biorefining technology that generates fiber for paper, board, packaging and other sustainable products whereas the latter generates cellulosic ethanol. In 2010, Chempolis started a biorefinery facility in Oulu after investing about 20 million Euros. The facility is able to process some 25 000 t/y of non-wood biomass. The facility is also able to run the test for its clients' samples (Chempolis n.d.).

UPM coordinates the FibreEtOH project which aims to demonstrate ethanol production based on paper fiber on a commercial scale. Production has been demonstrated in pilot scale (BiofuelsTP n.d.).

Ethanol from hemicellulose in sulphite pulp mills

Historically, ethanol from wood raw material has been produced in sulphite pulp mills. The ethanol is produced from sugars – primarily from hemicellulose – that is separated from the cellulose in the pulping process. In the middle of the 20th century, there were 32 Swedish mills producing approximately 60'000 tonne ethanol per year (Persson 2007). Today, only the **Domsjö mill** remains, producing 14000 tonne per year (Domsjö 2012b).

Academic research

Sweden

Several academic institutions perform research related to cellulose hydrolysis and ethanol production, for example **Lund University, Chalmers, Umeå University**.

Ethanol-related research is also performed within the framework of the **Swedish Knowledge Centre for Renewable Transportation Fuels (f3).**

Finland

Many research organisations are performing research related to production of wood based ethanol, for example, **VTT**, **University of Helsinki**, **Åbo Akademi University** and **Lappeenranta University of Technology**.

Gasification

Existing installations

Sweden

There is a number of existing gasification installations for biomass fuels in Sweden. One of these gasifies black liquor from a sulphate pulp mill and the others are solid biomass gasification installations. The only commercial installation is a 32 MWth bark gasifier at the Södra pulp mill in Värö installed in the 80s to replace fuel oil in the lime kiln (Hrbek 2011). Other existing gasification plants are pilot or demonstration plants in the capacity range of 0.15-18 MWth.

Chemrec black liquor gasifier (DP1) and DME synthesis pilot. The black liquor gasification plant is a pressurised (30 bar), oxygen-blown entrained flow gasifier rated at 3 MWth capacity (Nominal capacity is 20 tDS black liquor/day) (Chemrec n.d.). The plant is located at the Smurfit Kappa kraftliner mill and the ETC research centre in Piteå. A 4 t/d DME plant has been constructed next to the gasifier and field tests including 10 volvo trucks have completed a total of approximately 400000 km of DME-fuelled travel (BioDME n.d.).

MEVA wood powder gasification plant. A 500 kWth pilot and a 4 MWth demonstration plant aimed at small-scale CHP applications. The gasifier is fuelled with wood powder. It is air blown and not pressurize. The demo plant electricity output is about 1.2 MW (Brandin et al. 2011). The technology is based on a cyclone reactor, which produces a fuel gas that can be used to run a gas engine or turbine for small-scale cogeneration of heat and electricity. The technology has been developed by Luleå University of Technology and ETC, and is being commercialized by MEVA Innovation (Brandin et al. 2011)

IVAB pressurized entrained flow gasification plant (PEBG). Entrained flow gasifier for wood powder. A 1 MW, 15 bar pilot is located at ETC in Piteå. The technology is being commercialized by IVAB (Waldheim 2012).

Mid Sweden University indirect gasification lab. Mid Sweden University runs a 150 kW demo plant for indirectly heated gasification using a circulating fluidized bed gasifier. A synthesis unit is included to demonstrate motor fuel production (Waldheim 2012).

Wood roll test unit. A 500 kW plant applying indirect gasification. Has recently been relocated from Stockholm to Köping. The wood roll technology is being commercialized by Cortus AB (Waldheim 2012). Production of clean gas has been reported (Cortus AB 2012) and the process is designed to be fuel flexible (Cortus 2012).

KTH lab-scale gasification. There is a number of smaller-scale gasification test units at KTH, Stockholm: 75 kW pressurized (30 bar) & air & steam/oxygen FB gasifier with secondary reactor; 50 kW air & steam/oxygen FB gasifier; 5 kW air & steam/oxygen FB gasifier. There is also related analysis and reactor equipment (Waldheim 2012).

Chalmers CFB-coupled indirect gasifier. A 2-4 MWth indirectly heated gasifier integrated on the return leg of a Chalmers 12 MWth CFB boiler (Waldheim 2012).

Värnamo pressurized IGCC. Demonstration plant for biomass gasification and combined cycle electricity generation. Pressurized (18 bar) circulating fluidized bed with 18 MW fuel input producing heat (9MW) and electricity (6 MW). The plant was mothballed in 2000 after successful demonstration. A recent initiative to rebuild the plant for production of hydrogen-rich synthesis gas was ended after failure of closing the industrial funding target. The plant has now been mothballed again (Waldheim 2012).

Värö lime kiln gasifier. 32 MWth bark gasifier at the Södra pulp mill in Värö installed in the 80s to replace fuel oil in the lime kiln (Hrbek 2011). The gasification plant uses circulating fluidized bed technology (Waldheim 2012).

Finland

NSE biofuels Oy, a joint venture between Neste Oil and Stora Enso, opened a demonstration plant at Stora Enso's Varkaus Mill in Finland in 2009, which includes a 12 MW gasifier. Currently, NSE biofuel takes forest residues from Stora Enso's Varkaus mill and gasifies into syngas, which is provided to Stora Enso's limekiln. The main goal of NSE biofuel for the future has been to implement the first Biomass-to-Liquids (BTL) plant for commercial liquid fuel (Stora Enso 2009).

In August 2012 Neste Oil and Stora Enso announced that they decided to cancel the project to build the biodiesel plant. The two companies applied for funding under the EU's NER300 programme, but the project was not in the list of projects to receive funding (Neste Oil 2012).

Lahti Energy's Kymijärvi II power plant, opened in spring 2012, is a gasification power plant that generates electricity and district heat from Solid Recovered Fuel (SRF). The raw material of the SRF is energy-containing waste. The power plant produces 50 MW of electricity and 90 MW of district heat. In 1998, a traditional coal fired Kymijärvi I power plant was provided with an extra gasifier in order to gasify the biomass alongside coal and natural gas. The biomass gasifier accounts for about 15-20 % of total input (Lahti Energia n.d.; Lahti Energia n.d.).

Vaskiluodon Voima Oy is building a world's largest, 140 MW output biomass gasification plant in Vaasa. The plant is complete in 2012 and enables the company to replace about 25 – 40 % of its coal with domestic biofuels (Vaskiluodon Voima n.d.).

Metsä Fibre Oy is building a 48 MW gasification plant in their pulp mill in Joutseno. The plant starts production in autumn 2012, and uses bark as a fuel (Metsä Fibre n.d.).

In Finland, there also exist companies developing and manufacturing gasifiers suitable for smaller scale combined heat and power production.

CCM-Power Oy, a company located in Oulunsalo, provides dryer systems and develops wood gasification technology (CCM Power n.d.).

Gasek Oy, a company placed in Reisjärvi, is developing and manufacturing CHP plants based on gasification technology. For example, **Centria University of Applied Sciences** has their 150 kW (50 kW_e + 100 kW_{th}) pilot downdraft gasifier for research purposes located in Sievi, Finland (GASEK n.d.).

Entimos Oy in Tervola manufactures gasification-based CHP-plants with 1 – 7 MW output (ENTIMOS n.d.).

Planned scale-ups
There are also several projects planning for larger-scale gasification plants (Hrbek 2011). These projects are more or less far advanced, but none have yet reached the construction phase.

Sweden

Vallvik biofuel. The pulp and paper company Rottneros are seeking to build a black liquor gasification plant at their sulphate pulp mill in Vallvik (Rottneros 2012). They have applied for an investment grant from the NER300 program, in the category of ”Feedstock from lignocellulose, for example black liquor and/or pyrolysis or torrefaction, via entrained flow gasification to biofuels with a capacity of 40 million liters of end product per year”. The specified end production is methanol (STEM 2011).

The project was not prioritized for NER300 support, and its realization remains uncertain.

Rottneros biorefinery. Rottneros is also seeking to build a forest biomass gasification plant at their mechanical pulp (CTPM and groundwood) mill in Rottneros. They are applying for a NER300 grant in the category ”Lignocellulosics to biofuels or bioliquids and/or energy via gasification through direct heating, with a capacity of 15 million liter of end product or 100 GWh electricity per year”. The specified end product is methanol (STEM 2011).

The project was not prioritized for NER300 support, and its realization remains uncertain.

WoodRoll Köping. Cortus AB is commercializing their WoodRoll gasification technology. A contract has been signed with Nordkalk for delivery of gas. A 5 MW unit is planned for, with upscaling to 25 MW in a second step (Cortus 2012; Waldheim 2012).

Värmlandsmetanol Hagfors. Plans for 100000 t/a methanol production plus 15 MW district heat. The technology is based on fluidized bed gasification of forest biomass. Värmlandsmetanol claims that construction will start as soon as all permits are in place (Waldheim 2012). Uhde Gasification has been selected as technology supplier and engineering partner (Värmlandsmetanol 2010).

EON/SAKAB/Värmlandsmetanol Norrtorp. A pre-study was started in 2011 for a gasification plant co-producing totally 250 MW of methanol and SNG plus MW heat (SAKAB 2011).

GoBiGas Göteborg. Göteborg energi AB is constructing a 20 MW plant for the production of SNG and district heat. The plant applies indirectly heated gasification. The purpose of the plant is to demonstrate and study the technology and it is expected to be in operation in early 2013 (Waldheim 2012). An 80-100 MWth unit is planned for a second phase. Göteborg Energi AB has applied for a NER300 grant in the category ”Lignocellulosics to SNG or syngas and/or energy via gasification with a capacity of 40 million Nm3 product or 100 GWh electricity per year” (STEM 2011).

The project was on the list of prioritized projects to achieve NER300 funding.

EON Bio2G Malmö/Landskrona. E.ON is seeking to build a plant for biomass-based SNG production through gasification with planned start of operation in 2015. The unit would have up to 200 MW SNG production capacity. Two location alternatives are being investigated – Landskrona and Malmö (E.ON 2012). E.On Gasification Development have applied for an NER300 grant in the category ”Lignocellulosics to SNG or syngas and/or energy via gasification with a capacity of 40 million Nm3 product or 100 GWh electricity per year”. The specified end-product is SNG for heat and motor fuel (STEM 2011).

The project was on the reserve list of projects to achieve NER300 funding.

Advanced plans for scale-up of the **Chemrec black liquor gasification** technology at the **Domsjö biorefinery** in Örnsköldsvik have just recently (May 2012) been cancelled**.** The plans involved a 200 MW_{th} black liquor gasifier with methanol/DME production. Public co-funding from the Swedish Energy Agency had been secured, but Aditya Birla, owner of Domsjö since 2011, chose not to go further with the plans.

Finland

UPM has selected Rauma, Finland or Strasbourg (Stracel), France as two possible locations for a future biorefinery, which will produce FT-diesel. Rauma was selected because of its efficiency in energy, lower investment, compared to Kuusankoski. However, the company has not made any decision about the investments. The raw materials will be logging residues, stumps, barks and energy woods. Environmental impact assessment (EIA) has been completed for Rauma but for Strasbourg, is yet to be completed. The company has applied for NER300 financial support (UPM 2011).

UPM's Stracel BtL project was top-ranked in the NER300 list, while Rauma BtL project was left in the reserve list.

Forest BtL, a project originally owned by **Metsä Group** and **Vapo Oy**, with plans to build a plant for synthetic liquid biofuels based on gasification of biomass and Fischer-Tropsch synthesis. Metsä Group recently decided to withdraw from the project, and Vapo Oy is now seeking for new partners to continue the project (FTP 2012). The planned production capacity is approximately 100,000 tons of liquid biofuels per year. The raw material would be approximately 1.2 million tons of wood-based biomass and 30,000 tons of lignocellulosic bioliquids every year. Biodiesel or bionaphtha with possible cogeneration of electricity and heating are the expected end products (Metsä Group & Vapo Oy 2012).

Forest BtL applied for NER300 grants, and was among the top-ranked projects to be given funding.

Metsä Fibre together with energy companies **Gasum** and **Helsingin Energia** have been investigating a possibility to build a gasification plant at Metsä Fibre's Joutseno pulp mill. The plant is to use wood-based biomass, e.g. wood chips, to produce SNG (Gasum et al. 2012).

Research

Sweden

Swedish gasification centre (SFC) is a research centre where a number of academic stakeholders cooperate with the industry and has a total budget over 10 years of 540 million.

Operations in the SFC is conducted at three nodes, where three different gasification technologies are being studied

- CDGB - Direct gasification
  - Royal institute of technology (KTH)
  - Mälardalen University (MDH)
  - Linaeus University (LNU)
- CIBG - Indirect gasification
  - Chalmers University of Technology
  - University of Gothenburg(GU)
  - Mid Sweden University (MIUN)
  - SP Technical Research Institute of Sweden (SP)
- Bio4G - Suspension Gasification
  - Luleå technical university (LTU)

  - Umeå University (UmU)
  - Energy technology centre in Piteå (ETC)
  - Lund University, faculty of engineering (LTH)
- Private/industrial partners include:
  - Pite Energi, Fortum, Holmen, E. ON, Sveaskog, Mälarenergi, Chemrec, EEM, SCA, Cortus, Luleå Energi, Nordkalk, Skellefteå Kraft, Nynäs, Smurfit Kappa, AH, IVAB, SP, Meva Innovation, Metso, Northern Light, Göteborg Energi, Bioendev, Vattenfall

(SFC 2012)

Gasification-related research is also performed within the framework of the **Swedish Knowledge Centre for Renewable Transportation Fuels (f3)** (F3 2012)

Swedish gas centre (Svenskt gastekniskt centrum, SGC) co-ordinate Swedish industrial interest in R&D concerning gas fuel technology. This is done on a "non profit"-base. The Swedish government represented by Swedish Energy Agency participates in financing the R&D-program. SGC was established in 1990 and is owned by E.ON Gas Sverige AB, E.ON Sverige AB, Göteborg Energi AB, Lunds Energikoncernen AB, Öresundskraft AB and The Swedish Gas Association. SGC has a staff of 6 and an annual turnover of approximately 2.2 MEuro (SGC 2012).

Finland

Research organizations working in the field of gasification include for example **VTT, Aalto University,** and **Lappeenranta University of Technology**.

Pyrolysis and torrefaction

Pyrolysis is studied and developed within gasification research and development, as a part of the gasification process, but also as a separate technology, or as pre-treatment for further processing.

Sweden

Little information is found on pyrolysis projects in Sweden. However, there appears to be significant interests in pyrolysis from the industry (Alice Kempe, personal communication), and some of the industrial activities may be confidential.

Billerud AB has applied for a NER300 grant for the project **Pyrogrot** in the category ”lignocellulosics to intermediary solid, liquid or slurried bioenergy carriers via pyrolysis, with a capacity of 40000 tonne end product per year”. The end product of pyrogrot is pyrolysis oil.

The Pyrogrot project was top ranked for NER300 support.

Forest company **Sveaskog** has expressed a large interest in small-scale pyrolysis for primary refining of forest biomass close to the source (Lindstrand 2010).

Some development of pyrolysis is perfomed at **Energy Technology Centre in Piteå (ETC)** and at the **Royal Institute of Technology (KTH)**.

Torrefaction demonstration projects are ongoing at two locations in Sweden. In Umeå, there is a 20 kg/hour pilot equipment and a industrial scale demo plant is planned next to the **Umeå Energi** CHP plant. The torrefaction technology is being developed and commercialized by **BioEndev AB,** and related research is performed at **Umeå University** (ETPC research group). **SLU** is performing pelletization trials of torrefied material.

The other torrefaction demonstration project is located in Klintehamn, Gotland, and is being run by **Torkapparater AB.**

There is an interest in torrefaction from forest owner companies, such as **Sveaskog** (Lindstrand 2010), and from energy companies. For example, **Vattenfall** sees biomass as direct replacement for coal in existing power plants as their main bioenergy priority, and is investigating torrefied biomass for this purpose (Vattenfall 2012).

Finland

Fortum released a statement in 2012 that it will invest for the commercialization of bio-oil and a plant producing bio-oil, which will be integrated to the company's combined heat and power production unit in Joensuu. The integrated bio-oil plant, based on fast pyrolysis technology, is the first of its kind in the world on an industrial scale. The plant's estimated production is expected to be 50,000 tons of bio-oil per year along with heat and electricity. The raw materials include forest residues and other wood based biomass. At the moment, Fortum intends to use produced bio-oil (210 GWh) in heat and power generation, but for a long run, it could be used as raw material for biochemicals and transport fuel (Fortum n.d.).

Metso has a 2 MW pyrolysis pilot plant (7 tons/d bio-oil) in Tampere for R&D (Lehto 2010).

Green Fuel Nordic Oy is a biomass processing company that deals with forest residues and agricultural residues converting them into 2nd generation bio-oil. In 2011, the company invested 150 million euros to construct three facilities that will utilize 1 million m^3 of total feedstock every year, which will generate about 270,000 tons of bio-oil. It will start from 2013. The company penned down on a contract with Envergent Technologies to utilize the patented pyrolysis technology called RTP^{TM} in Finnish biorefineries under construction (GFN n.d.).

Pulp mill based biorefineries

Pulp mills, in general, use advanced processes to separate wood into pulp fibres. As such, they could be said to be biorefineries already. However, the focus has until recently been on one single product – the pulp – while residue streams have been used internally for energy.

There is now a large interest in developing new products, and virtually all existing pulp industries are working within this field. The focus of a particular mill depends on it prerequisites. The biorefinery approaches will vary depending on the pulping technology used; sulphate pulping, sulphite pulping or mechanical pulping.

At least four main approaches – which could also be combined – could be identified:

1) Development of the pulp fibres into new types of materials and products, for example:
   a) Cellulose fibres for textiles etc. Currently produced by **Domsjö**. Production has recently started also by **Södra** (Södra 2012b).
   b) Durapulp – a composite material made by **Södra** (Södra 2011; Södra 2012a), from cellulose pulp and polylactic acid (PLA).

      Nanocellulose – or microfibrillated cellulose (MFC). Tiny fibrils produced from cellulose. Believed to have many potential uses (Innventia n.d.). Under development by, for example, **Innventia** (pilot production facility), **KTH** and **LTU**. In Finland VTT, Aalto University and UPM cooperate in **The Finnish Centre for Nanocellulosic Technologies. Stora Enso** and **UPM** have started microfibrillar cellulose production operations.
   c) Other applications could be filter materials, cellulose derivatives for medical or chemical applications and biocomposite materials. Related research has been performed by, for example, **KTH** (Dep. of Fibre and polymer technology) and **LTU** (Nanoselect project). **Akzo Nobel** develops products from cellulose derivatives.

2) Upgrading of residue streams to marketable products, for example
   a) Lignin: Lignosulfonates **(Domsjö)**, Lignoboost **(Metso/Innventia)**, black liquor gasification **(Chemrec)**, carbon fibres **(Innventia)**.
   b) Hemicellulose: Fermentation to ethanol (**Domsjö**, from sulphite liquor), production of polymers and barrier materials **(Innventia).**
   c) Fibre sludge etc: Hydrolysis and fermentation to ethanol. Also other uses investigated **(Domsjö)**. Gasification **(TMP mills, MIUN)**. Nanocellulose production (**LTU**)
3) Energy integration of new processes, which co-produce process steam and marketable products, for example
   a) Gasification of logging residues and internal residues to produce motor fuel and steam. Mostly an alternative for mills that has a larger steam demand than what can be supplied from internal residues and waste heat (e.g. integrated pulp and paper mills).
   b) Pyrolysis of logging residues and internal residues to produce pyrolysis oil, char and steam. Pyrolysis oil could be used to replace fuel oil, or upgraded to higher value fuels and chemicals. Mostly an alternative for mills that has a larger steam demand than what can be supplied from internal residues and waste heat (e.g. integrated pulp and paper mills).
4) Pre-processing/extraction of incoming raw material to produce fuels or chemicals, for example
   a) Extraction of hemicellulose from wood chips, prior to pulping, for fermentation to ethanol or for use as chemicals.

In many of these approaches, heat integration between existing pulping processes and new or developed processes is important. Research on integration issues is done, for example, at **Chalmers.** Other integration benefits, for example concerning raw material handling, could also be of importance.

Innventia is a research and development company that has its roots in forest industry and packaging industry research institutes, and is a central actor for pulp-mill based biorefinery development in Sweden. In Finland, the Forest industry research institute (KCL) was merged into **VTT** in 2010. VTT performs research related to most biorefinery aspects, including pulp-mill based biorefineries.

Forest industry companies also have their own research and development activities in this field. Some research activities are performed within the **Processum cluster** (Sweden).

Most **universities** have research relevant to pulp-mill based biorefineries. Examples of university-based centers are the **Wallenberg Wood Science Centre** (KTH and Chalmers), **Fibre Science and Communication Network** (Mid Sweden University) in Sweden.

Similarly, many universities and other research organizations in Finland are performing research activities related to pulp-mill based biorefineries.

Other

Sugar platform chemicals
A wide variety of chemicals could be produced from cellulose and hemicellulose sugars. Examples of interesting sugar-derived chemicals that could act as precursors for a range of intermediate and final products are: Ethanol, succinic acid, itaconic acid, levulinic acid, glycerol, among many others.

Sweden

Related research is performed, for example, by **SEKAB E-technology/Processum** network and universities, e.g. **Luleå Technical University**, **Chalmers**, **Lund University**.

Finland

Examples of research organizations in Finland working in the field of producing green chemicals include **VTT**, **University of Helsinki, Åbo Akademi University** and **University of Oulu.**

Lignin platform chemicals

More potential uses have been found for cellulose and hemicellulose than for lignin. In sulphate pulping, lignin in black liquor is typically used for energy recovery. The ligniboost process, developed by **Innventia** and owned by **Metso**, separates lignin from the black liquor. Currently, this lignin has no large-scale uses outside energy applications (Metso 2012).

Lignosulphonates from sulphite pulp mills (e.g. **Domsjö**) are typically used as concrete additives in the construction sector.

Lignins could be used as phenols, in resins, and other chemical uses, including aromatic fine chemicals. **KTH** and Innventia are researching the production of carbon fibres from lignin. Also other uses of lignin investigated at KTH (Division of Wood chemistry and pulp technology). Also other universities (e.g. **Lund University**) have research activities related to lignin. New products from lignin are investigated in the **Processum** cluster.

Biomass-based chemicals for petrochemistry

The petrochemistry cluster in **Stenungsund** is working for the vision of “Sustainable chemistry 2030”. One part of this is to move towards feedstock based on renewable origin. Methanol, butanol and olefins are three base chemicals that the industry is interested in acquiring from renewable sources.

Tall oil

Sweden

Tall oil consists of extractives obtained in chemical pulping. It is used as fuel replacing fuel oil. **Sunpine** in Piteå produces crude tall diesel. This is further refined by **Preem** into diesel fuel, which is blended with conventional diesel. **Arizona Chemical** has a tall oil refinery in Sandarne, producing a range of chemicals.

Finland

UPM is to invest in a facility for production of biofuels from crude tall oil in Lappeenranta under the brand name BioVerno. Planned capacity is 100’000 tonne of tall oil diesel per year. Most of the raw material comes from UPM’s pulp mills. The construction starts in 2012 and will be completed by 2014 (UPM n.d.).

Forchem is a Finnish producer of tall oil based chemicals with operations in Rauma.

Other extractives/naturally occurring chemicals

There are a huge number of small-volume substances in forest biomass that could be recovered and used in high-value applications. Examples of areas of applications are within medicine, plant growth stimulation, vermin repellents and many more. Related research is performed at, for example **Mid Sweden University** (Department of Natural Sciences, Engineering and Mathematics), **SLU** (Unit of Biomass Technology and Chemistry) and others.

The **Jegrelius archive**, managed by the Jegrelius institute, Östersund, contains a collection of historic documents on biological chemicals and green chemistry in general, with a focus on analytical chemistry, toxicity and risk assessment.

Biocomposites
Fibres and polymers derived from biomass can be combined into composite materials with designed properties.

Sweden
Important research institutions are **Swerea SICOMP**, **Innventia**, **Chalmers**, **KTH**. Pulp producer **Södra Cell** are developing new, cellulose-based materials and have a product called Durapulp.

Finland
Onbone Oy manufactures casts from wood chips and biodegradable plastic. Finnish innovation Woodcast was granted the Chemical Industry Innovation Award on 23 April 2012 (Onbone n.d.).

UPM has also developed composite materials such as UMP ProFi and UMP ForMi, that combines cellulose fibres and plastic and clean polymers and pulp, respectively (UPM n.d.).

Wood pellets energy combines
There are two plants for co-production of wood pellets, heat and electricity in Sweden (Nohlgren et al. 2012). They are located in Storuman and Hedensbyn (Skellefteå Kraft n.d.; Skellefteå Kraft n.d.). Both plants are owned by **Skellefteå Kraft.** The plant in Storuman was taken into operation in 2008 but is now closing down operations due to increasing raw material costs and weak pellets market (Skellefteå kraft 2012).

There are several pellet plants that are co-located with sawmills. The integration between pellet plants and saw mills is, however, limited to some exchange of hot water. The main reason for co-location is to utilize saw mill by-products as raw materials for pellet production (Nohlgren et al. 2012). Wood pellets production could be combined with other biorefinery processes; for example, the planned ethanol production facility in Sveg is intended to be integrated with an existing pellets plant and a CHP plant.

Non-wood based biodiesel
Sweden
Some biodiesel (FAME) is produced from rape oil in Sweden. **Perstorp bio products** (Perstorp bioproducts n.d.) and **Ecobränsle** (Ecobränsle 2012) are two main producers.

Finland
Neste Oil, a Finnish leading oil company in terms of liquid biofuel, especially the 2nd generation has developed its own process called NExBTL. This process produces biodiesel from palm oil, rapeseed oil and animal fat through hydrogenation and refining. Neste imports palm oil from Malaysia. Currently Neste Oil has two production units in Finland, Porvoo. The first production facility started in 2007 with a capacity of 170,000 tons of fuel per year and the second started in 2009 with similar output. Currently both facilities produce 170,000 tons of diesel per year. The plant needs 200,000 tons of raw materials per year. The domestic raw material, rapeseed and tallow accounts for 20,000 tons per year where as remaining accounts imported palm oil (Neste Oil 2011; Soimakallio et al. 2009).

Starch-based ethanol (“1st generation”)
Sweden
Ethanol production from starch and sugar crops is well-known. Today, ethanol is produced from cereal crops by Agroetanol in Norrköping. Two production lines have a total capacity of 210’000 m3 ethanol per year. The plant has some energy integration with a nearby heat and power plant. Besides ethanol, animal feed and CO_2 is produced (Agroetanol 2012; Haaker 2010).

A plant for production of ethanol and biogas from cereals is planned by Nordisk Etanol & Biogas. An ethanol production of 130000 m^3 per year with gradual scale up to 260000 m^3 per year is envisaged (Nordisk Etanol & Biogas 2011; Haaker 2010)

Finland

Suomen Bioetanoli Oy plans a bioethanol plant in Punkaharju, Finland. Expected date of operation is end of 2012. The feedstock will be 228 000 tons of barley per year and generate about 75000 m^3 ethanol per year. On the other hand plant will generate a by-product of 60 000 tons/year, which can be used as a feed for cattle. The feedstock will be provided sufficiently by some 70 000 hectare of farm (SBe n.d.)

Ubio Oy is planning a bioethanol plant in Uusikaupunki, which would produce bioethanol 83 million litres/year from wheat. In addition, the plant would recover gluten for food industry and residues from the process could be used as animal feed. The production of bioethanol would start at the earliest in the 2014 (Huittinen 2012).

Wood tar and charcoal

There are a few producers and distributors of wood tar and charcoal. See, for example Auson (Auson AB n.d.), Claessons (Claessons n.d.) and Vindelkol AB (Vindelkol AB n.d.).

Discussion and conclusions

The concept of biorefining covers a wide range of possible industrial activities, which is also reflected in the variety of development paths followed in current projects. Industrial complexes that utilize all components of a tree are plausible, as well as specialized industries that process only specific tree parts. It is also conceivable with an industry structure where the majority of the industries process by-products from a few types of industries that process primary forest raw material. Existing pulp mills or future large-scale biofuel plants are examples of candidates for such primary forest raw material processing industries.

The forest biomass resources are extensive in Sweden and Finland, but each alternative biorefinery structure puts different demands on the raw material supply chain. However, today it is not known what tree- and wood components will meet the demands of the whole biorefinery industry. Neither is it known how the logistical systems from the stump to the plant will affect the quality of the desired feedstock. It is the industry and the end product which will set the requirements on the physical and chemical composition of the forest biomass. The continued study of different supply chain and biorefinery options could help forest owners and biorefinery stakeholders in making the right priorities for the future.

This document is the pre-study report of the Forest Refine project. It provides a screening of ongoing biorefinery activities in Sweden and Finland. There is no single definition of what a biorefinery is. Therefore, this initial study has had a wide scope, but with a main focus on

> *New, non-conventional processes for refining of forest biomass (i.e. not on conventional heat, CHP, pulp production, etc.), integrated production of multiple products and on the utilization of new forest biomass assortments. Focus is further on value chains containing some steps of decomposition of the raw material on a chemical level, and not on value chains containing only mechanical processing.*

Much of the information is collected from web pages and secondary sources, such as reports and news articles. This information may be outdated or incomplete. Future work within the Forest Refine project will follow up and verify the most interesting developments.

Biorefining is a wide field encompassing several processes and products has a variety of stakeholders with different interests, who are involved in the development. In general, existing industry is interested in developing processes that fits into their existing business. There is often a local/regional interest in biorefinery development projects as a means to create employment and increase the value of forest resources. The development of ligno-cellulosic motor biofuels appears to have mostly been performed by university research and public funding. The pulp industry is a large commercial player that seeks to develop their current business. This involves integration of gasification or pyrolysis to co-produce value added products with the process heat supply, upgrading of by products and finding new uses for the pulp product, such as composite materials. Development of cellulose ethanol production, on the other hand, is of smaller interest to the pulp industry, since most of the cellulose is maintained in the pulp. The cellulose ethanol development has instead been driven by university research and demonstration plants have been erected by development companies supported by public funding and by energy industries. Two large energy industries in the south of Sweden are interested in gasification technology for methane production, which will be injected in the natural gas network that covers the southern part of Sweden. One methane demonstration plant is being built, and investment support applications have been filed for larger-scale plants.

The petroleum industry is starting to show interest in bioenergy and, for example, Preem is marketing a diesel produced from tall oil and Neste Oil has been cooperating with Stora Enso in gasification and Fischer Tropsch synthesis development. The petro-chemical industry has also recently started to more intensively investigate the possibilities to acquire biomass-based base chemicals. Extraction of small-volume natural compounds and chemicals from forest feedstock appears to be more of a niche area of development. Forest industry is showing some interest in this area and a couple of research groups are active.

Conclusion

Although there is no unique definition of a biorefinery, it is clear that it is a facility for refining of a biomass feedstock into useful and valuable products. As such, refining of forest feedstock is nothing new. Rather, the current biorefinery development should be seen in the light of present driving forces such as climate change reduction requirements, increasing energy prices, raw material competition, competition in traditional forest products markets, demand changes and technical developments. Furthermore, competition and industry transformation is not unique for our time, and whoever has the best strategy to meet these challenges has a good chance of survival and being the leader of the forest industry development.

From the present review of biorefinery initiatives, it is clear that there is no lack of activities related to biorefining in Finland and Sweden. To bridge the gap, from research and development projects to larger-scale, commercial demonstration projects, has proven to be a challenge. One reason is that biomass-based products in many cases are not economically competitive compared to other – often fossil-based – alternatives, under current market conditions. Another reason is the risks inherent in large-scale industrial investments, especially with new technologies. The success of such projects is dependent on a number of parameters outside of the control of the individual project developer. One type of uncertainty relates to future economic conditions, including market prices and public support policies. Another type relates to the complexity of integrating a new large industry into existing structures. A project may for its success depend on, for example, the development of the local district heating network. Instruments for handling uncertainties may prove important for the successful establishment of large-scale greenfield biorefineries. Large upfront investment requirements make financing a difficult task, given the mentioned economic and technical uncertainties. Investment support instruments, such as the NER300, may help to overcome this. It is therefore likely that we will see industrial scale demonstration plants for at least some of the biorefinery concepts discussed in this review. Judging from the first call of the NER300 program, projects developing the thermochemical pathways of pyrolysis and gasification are more likely to be pursued than biochemical pathway projects in Sweden and Finland in the near future. The situation may be somewhat different for biorefinery concepts which can grow incrementally from existing industries – such as pulp mills and energy industries – and in these industries there is a lot of activity ongoing within research and development, but we have also seen a number of non-conventional products already reach commercialization.

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Annex

A1. Time lines

Some important milestones in the development of two refining industry brances – oil refining and corn wet milling are given in Annex table 1. These industry branches are described primarily from a Nort-American perspective (Lynd et al. 2005). Also included are historical milestones for two existing, biorefinery-related, Swedish companies: Chemical producer Perstorp industries, which developed from a wood refining industry but who is now mainly using fossil feedstock in their processes, and the Domsjö specialty cellulose mill, which developed from a sulphite pulp mill and is now producing a range of products based on cellulose pulp, lignin and ethanol.

Annex table 1. Historical development of two refinery industry branches (left) and two Swedish, biorefinery related industry companies (right)

Oil refining	Corn wet milling	Perstorp industry	Domsjö industry
1861 First petroleum refinery opens, producing kerosene—a better and cheaper source of light than whale oil—by atmospheric distillation. Naptha and tar produced as by-products.	1844 Wm. Colgate & Company builds first dedicated corn starch plant. 1866 Dextrose produced from corn for the first time.		
1870 Vacuum distillation developed, enabling production of lubricating oils. Asphalt produced as by-product.	1882 Refined anhydrous sugar first manufactured. Industry also begins producing corn gluten feed, realizing the value of non-starch parts of corn.	1880's: Wilhelm Wendt registers a company, intending to produce acetic acid, tar, charcoal and wood alcohol.	
1890s The emergence of the internal combustion engine creates demand for diesel fuel and gasoline; demand for kerosene declines with the invention and proliferation of the electric light.	1889 First commercial production of corn oil. 1893 Industry begins recovering and condensing steepwater for use in feed products.	1890's: Wendt increases the refinement and utilization of raw materials yielded by charcoal burning. This leads to the increased use and refinment of every possible waste product from the distilleries.	
1913 Thermal cracking developed—in response to increased demand for gasoline due to mass production manufacturing and the outbreak of World War I—enabling refiners to produce additional gasoline and distillate fuels by subjecting heavy crude fractions to high pressures and temperatures.	1921 Corn syrup technology advances significantly with the introduction of enzyme- hydrolyzed products such as crystalline dextrose hydrate.	1900's: Production of formalin begins. Production of creosote becomes an important source of revenue, and the Russo-Japanese War means that all creosote is sold to the Japanese army. 1910's: World War I creates a boom in acetic acid sales. Perstorp begins producing its own glassware to meet demand for bottles. 1920's: The budding radio and electrical industries in Sweden become large consumers of plastic substances, such as Perstorp's Isolit. Production of laminates begins.	1903 Production started in the Domsjö pulp mill
1930s Many advances made to improve gasoline yield and properties in response to development of higher-compression engines: catalytic cracking, thermal reforming, and catalytic polymerization to improve octane number; hydrogenation to remove sulfur; coking to produce gasoline basestocks; solvent extraction to improve viscosity index; and solvent dewaxing to improve pour point. By-products produced include residual fuel oil, coke, aromatics, waxes, and petrochemical feedstocks.		1930's: Perstorp introduces many new plastic products.	1930 Dissolving pulp production started 1936 Chlorine production plant taken into operation
1940s The demands of World War II spurred yet more refining innovations: alkylation, for example, which produced high-octane aviation gasoline and petrochemical feedstock for explosives and synthetic rubber, and catalytic isomerization, which produced increased quantities of alkylation feedstock.		1940's: The Second World war created a need for quality coal to generate gas for automobiles. Perstorp's economy receives a boost, as a new charcoal-burning plant has just been built. At the end of the war, Perstorp emerges as Scandinavia's first modern plastics industry, with more than 10.000 different products, ranging from billiard balls to aerial masts.	1940 Construction of an ethanol plant
1950s-70s Following the war, various reforming processes were developed to improve gasoline quality and yield and produce higher-quality products: deasphalting, catalytic reforming, hydrodesulfurization, and hydrocracking, for example.	1950s Technology for commercially preparing low conversion products such as maltodextrin developed. For the first time, corn-based sweeteners could compete in some sugar industry markets. 1967 First commercial shipment of high fructose corn syrup (HFCS) produced via enzyme catalyzed isomerization of dextrose to fructose.	1950's Transition to petroleum-based raw materials 1960's: Polyalcohols made from formalin become important products which Perstorp supplies the paint industry with.	
	1970s Fuel ethanol becomes a major product 1980s HFCS becomes the sweetener of choice for the U.S. soft drink industry. 1990s-present Industry focuses on developing new biologically produced products such as organic acids and degradable replacements for chemical products.	1980's: The company extends into new fields, such as biochemistry. Perstorp now launches Pergo, a laminate floor. 1990's: All non-chemical and materials technology operations are divested, and Perstorp focuses on the specialty chemicals area.	1979 Production of dissolving cellulose discontinued 1985 Biological waste water treatment plant taken into operation. Co-located plant for recovery and use of CO_2 started by AGA. 1990 Switch to chlorine-free bleaching. 1993 Re-start of dissolving cellulose propduction.
		2007 Production starts at Scandinavia's largest plant for renewable vehicle fuel, RME (rape seed methylester).	2000s The mill was sold to a private consortium and a strategy to develope towards a complete biorefinery was commenced 2009 first lignin dryer taken into operation

A2. NER300

NER300 is an EU instrument for financing of commercial demonstration projects that aim at the environmentally safe capture and geological storage of CO_2, as well as demonstration projects of innovative renewable energy technologies (European Commission 2010). It is funded by the sale of 300 million greenhouse gas emission allowances. The program is split into (at least) two calls. Applications for the first call has been prioritized and final decisions are expected by the end of 2012 (European Commission 2012).

Finnish applications in the first call

Three Finnish projects applied in the first call. These were:

- UPM Rauma BTL, a biorefinery which will produce FT-diesel, located in Rauma. UMP-kymmene has also applied for a similar project with an alternative location, in Strassbourg, France.
- NSE Biofuels Oy Ltd, a joint venture of Neste Oil and Stora Enso applying for an FT-fuel plant.
- Ajos BTL, originally applied for by Forest Btl Oy – a joint project of Vapo Oy and Metsä Group to build a plant for FT fuels in Kemi/Ajos. Metsä Group has withdrawn from the project.

Of projects Forest Btl Oy’s project was the only prioritized Finnish project on the prilimnary list released in July 2012. UPM was also oni the priority list, but with the Strassbourg location as the first-hand alternative and Rauma on the reserve list. After the release of the prioritisation list, NSE Biofuels decided to cancel their plans. Metsä group has also withdrawn from the Ajos BTL project and Vapo Oy are seeking new partners to go forward with the project.

Swedish applications in the first call

- Pyrogrot - Billerud AB applied for a pyrolysis plant at one of their pulp mills, with pyrolysis oil as the end product.
- Vallvik Biofuel - Rottneros AB applied for a black liquor gasification plant at their Vallvik mill, with methanol as the end product.
- Rottneros Biorefinery – Rottneros AB applied for a biomass gasification plant at their Rottneros mill, with methanol as the end product.
- E.ON Bio2G Sweden - E.ON Gasification Development applied for a biomass gasification plant with methane as the end product.
- GoBiGas 2 - Göteborgs Energi AB applied for a biomass gasification plant with methane as the end product.

There were also four applications from projects developing other renewable energy sources than bioenergy

- Vindpark Blaiken - Blaiken Vind AB, applied within on-shore wind energy.
- Hexicon Baltic - Hexicon AB applied within off-shore wave energy.
- Smart Grid Gotland - Gotlands Energi AB applied for a project optimising the use of renewable energy through smart electric grids, focusing on wind energy
- MTCT - Multi-megawatt Turbines in Complex Terrain - Svevind AB applied within on-shore wind energy

(STEM 2011)

Pyrogrot was top ranked in the preliminary priority list, and GoBiGas 2 was also ranked high, with E.ON Bio2G on the reserve list. Vakkvik biofuel and Rottneros Biorefinery were not prioritized, and it is not clear whether Rottneros will pursue these projects.

First call preliminary prioritisation

Candidates for award decision (top-ranked projects)			Reserve list (second-ranked projects)	
Member state	Project category	Project	Member state	Project
SE	Bioenergy	Pyrogrot		n/a
SE	Bioenergy	GoBiGas Phase 2	SE	EON Bio2G
IT	Bioenergy	BEST	PL	CEG Plant Goswinowice
SE	Wind	Vindparken Blaiken		n/a
FI	Bioenergy	Ajos BTL	NL	Woodspirit
AT	Wind	Windpark Handhalm	SE	Multi-megawatt turbines
EL	CSP	MINOS	ES	PTC50-Alvarado
PT	Ocean	SWELL	IE	WestWave
SE	Distributed renewable management	Smart Grid Gotland		n/a
FR	Bioenergy	UPM Stracel BTL	FI	UPM Rauma BTL
DE	Wind	Innogy	DE	Veja Mate I
CZ	Geothermal	Litomerice		n/a
PT	PV	CPV Portugal		n/a
EL	CSP	MAXIMUS	CY	Helios Power
UK	Ocean	Sound of Islay	UK	Kyle Rhea
BE	Distributed renewable management	SLim		n/a
DE	Bioenergy	VERBIO Straw	DK	IKA2
HU	Geothermal	South Hungarian		n/a
PT	Wind	Windfloat	FR	VertiMED
EL	PV	PV Megapolis		n/a
IT	CSP	Archetype 30+		n/a
FR	Ocean	ETM Martinique		n/a

(European Commission 2012)

A3. Biorefinery research projects

The Star-COLIBRI database

The research project Star-COLIBRI has set up a database for biorefinery-related research projects. The database is available at http://www.star-colibri.net (Star-COLIBRI 2012)

The database consists of 381 projects with a total budget of 1323 M€.

Annex table 2. Total project budget data from the Star-COLIBRI database

Public funding			Total budget		
Average	Sum	Median	Average	Sum	Median
5 791 212,64	637 033 390,00	2 085 000,00	10 022 912,83	1 323 024 494,00	2 700 796,50

Annex table 3. Selected projects. Projects with budget >10 M€ and projects with Finnish and/or Swedish partners are listed. The project coordinator is listed if it is a Finnish or Swedish organisation.

Total budget	SE	FI	Short name	Name	Coordinator
		X	A sustainable and high-efficiency process for conversion of solar energy into transport fuel	A sustainable and high-efficiency process for conversion of solar energy into transport fuel	University of Turku
11	X	X	AFORE	Added-value from chemicals and polymers by new integrated separation, fractionation and upgrading technologies	VTT, Technical Research Centre of Finland
		X	AgroBio	Agro biomass by-products to multifunctional ingredients, chemicals and fillers	Åbo Akademi University
	X		Aktivt kol från förnyelsebara råvaror	Active carbon from renewable raw materials	Innventia
		X	ALDIGA	Algae from waste for combined biodiesel and biogas production	
		X	ALGISEL	Algae for biodiesel production	
28			ALGOHUB	Exploitation and use of microalgae in Nutrition & Health	
13			ASPECT	Advanced Sustainable Processes by Engaging Catalytic Technologies Programme	
		X	BABETHANOL	New feedstock and innovative transformation process for a more sustainable development and production of lignocellulosic ethanol	
120			BE-Basic	Bio-Based Ecologically Balanced Sustainable Industrial Chemistry Programme	
		X	BEET	Electricity Markets, Emissions Trading and Incentives in Bioenergy Technology	
	X		BiBaPack	BiBaPack	Innventia
		X	Bio fuel oil: Component Development and Base Data Generation for an Emerging Biofuel Chain	Bio fuel oil: Component Development and Base Data Generation for an Emerging Biofuel Chain	
25	X		Bio4Energy	Bio4Energy	Umeå University
		X	Biobalance	Biobalance	Valcon
		X	BIOCAT	Modular Biocatalyst Platform for Chiral Synthesis of Chemical Compounds by Structure-based Directed Evolution	
		X	BIOCHEM	BIOCHEM	
20	X	X	BIOCORE	BIOCOmmodity REfining	
13	X	X	Biocoup	Co-processing of upgraded bio-liquids in standard refinery units	VTT, Technical Research Centre of Finland
28	X		BioDME	The BioDME project	Volvo Trucks
10			BioFAT	BIOfuel From Algae Technologies	
		X	BIO-FOAM	Biomass derived novel functional foamy	

				materials	
		X	BioForest	Commodity chemical from wood biomass	
		X	BioHap	Biomass-based production of low-molecular-mass aliphatic carboxylic acids	University of Jyväskylä
90			BioHub	BioHub	
	X		Bioimprove	Better trees for bioenergy and material production	Umeå Plant Science Centre
53			Bioliq® Pilot plant	Syngas biorefinery based on straw	
16	X		BIOLYFE	BIOLYFE	
	X		BIOPOL	BIOPOL	
		X	BIORAFF II	Chemistry in forest biorefineries II	Åbo Akademi University
	X		Bioraffinaderi för miljövänlig framställning av hållbart fiskfoder	Biorefineries for environmentally friendly production of fish feed	Nordic Paper
		X	Bioreducer	Bioreducer	University of Oulu
		X	Biorefineries- Future Business Opportunity for Forest Cluster	Biorefineries- Future Business Opportunity for Forest Cluster	University of Jyväskylä
		X	Biorefinery Euroview	Biorefinery Euroview	
	X	X	BIOREF-INTEG	Development of advanced biorefinery schemes to be integrated into existing industrial fuel producing complexes	
15	X	X	BIORENEW	White Biotechnology for added value products from renewable plant polymers: Design of tailor-made biocatalysts and new industrial bioprocesses	
		X	Bioscen	Modelling of the biorefinery scenarios	VTT, Technical Research Centre of Finland
28			BioSos	Biorrefineria sostenible - Sustainable Biorefinery	
		X	BIOSTIMUL	Bioactive and wood-associated stilbenes as multifunctional antimicrobial and health promoting agents	University of Kuopio
13		X	BIOSYNERGY	Biomass for the market competitive and environmentally friendly synthesis of bio-products together with the production of secondary energy carriers through the biorefinery approach	
	X		BIOTECHNICAL TRANSFORMATION OF INDUSTRIAL GLYCANS	BIOTECHNICAL TRANSFORMATION OF INDUSTRIAL GLYCANS	Lund University
112			BioTfuel	BioTfuel	
		X	BIOVAIKU	Environmental and economic implications of second generation biofuels for transportation	VTT, Technical Research Centre of Finland
		X	BIOVIRTA	Processing biogas plant digestates into value-added products	MTT, Agrifood Research Finland
		X	BiSe	Biorefinery pulp mill	Lappeenranta University of Technology
28	X		BornBioFuel 1 & 2	Cellulosic (2nd generation) bioethanol demonstration plant, proof-of-technology, core technology development (Phase 1) & Cellulosic (2nd generation) integrated bioethanol demonstration plant (Phase 2)	
11			BRISK	The European Research Infrastructure for Thermochemical Biomass Conversion	
		X	BTL-Liquid biofuels from biomass, part 3	BTL-Liquid biofuels from biomass, part 3	UPM
		X	CaDeWo	Catalytic decomposition of wood	
	X		CarboMat	CarboMat - The KTH Advanced Carbohydrate Materials Consortium	KTH
29			CATCHBIO	Catalysis for Sustainable Chemicals from Biomass Programme	
65			CBP - Chemical Biotechnological Process Centre	Bioraffinerie - Entwicklungszentrum	
	X		Cellunova	Cellunova	Karlstad University(?)
		X	Clean Engine	Advanced technologies for highly efficient clean engines working with alternative and lubes	
	X		Cluster Biorefinery II	Cluster Biorefinery II	Innventia
		X	CO2UTIL	Towards Utilization of Carbon Dioxide as a Green and Versatile Commodity Chemical: Clean Synthesis of Methanol and Dimethyl	

				Carbonate (DMC)	
		X	Conversion of pectin rich residues to D-galacturonic acid and other platform chemicals using solid state fermentation and metabolically engineered fungal microorganisms	Conversion of pectin rich residues to D-galacturonic acid and other platform chemicals using solid state fermentation and metabolically engineered fungal microorganisms	VTT Technical Research Centre of Finland
	X		Copower	Synergy effects of co-processing of biomass with coal and non-toxic wastes for heat and power generation	
21			DEINOL	DEINOL	
		X	Development of the production and utilization of first generation bio oils, Phase 2	Development of the production and utilization of first generation bio oils, Phase 2	Metso Power
		X	Development of the production and utilization of first generation bio oils, Phase 3	Development of the production and utilization of first generation bio oils, Phase 3	Metso Power
	X	X	DISCO	Targeted discovery of novel cellulases and hemicellulases and their reaction mechanisms for hydrolysis of lignocellulosic biomass	VTT, Technical Research Centre of Finland
		X	Economic-ecological optimization of timber and bioenergy production and sequestration of carbon in Norway spruce stands	Economic-ecological optimization of timber and bioenergy production and sequestration of carbon in Norway spruce stands	
		X	Efficient production of fuels from biomass	Efficient production of fuels from biomass	
	X		Enzymer som verktyg för tillverkning av nya produkter - resurssnåla processer för nya material	Enzymes as tools for production of new products - resource efficient processes for new materials	Lund University
37	X		EuroBioRef	EUROpean multilevel integrated BIOREFinery design for sustainable biomass processing	
		X	Feasibility of Finnish and Brazilian biomasses in advanced biorefineries	Feasibility of Finnish and Brazilian biomasses in advanced biorefineries	
		X	FOBIT	Forest-based fuel and material demand and the overall climatic impacts	
	X		Framställning av gröna bränslen och kemikalier via fraktionering av koklut	Framställning av gröna bränslen och kemikalier via fraktionering av koklut	Luleå Technical University
18		X	FuBio	Future Biorefinery	Forestcluster
		X	Functional Genomis of Tree Biomass	Functional Genomis of Tree Biomass	
		X	Functional natural fiber reinforced composites	Functional natural fiber reinforced composites	Elastopoli Oy
		X	FunMan	Targeted Functionalization of Spruce Galactoglucomannans with Aid of Galactose Oxidase	
		X	Future technologies of forest, energy and chemical industries	Future technologies of forest, energy and chemical industries	UPM
74			FUTUROL	FUTUROL	
	X		Förnyelsebara funktionella barriärer	Förnyelsebara funktionella barriärer	Karlstad University
	X		Förpackningar från funktionella och förnyelsebara hydrolysat	Förpackningar från funktionella och förnyelsebara hydrolysat	KTH
	X		GreenSyngas	Advanced cleaning devices for production of green syngas	Lund University
		X	HemiEx	Comparative evaluation of different hemicelluloses isolation processes integrated with alkaline cooking	Aalto University School of Science and Technology
		X	Hemu	Pressurized hot-water extraction of wood hemicelluloses	Metla, Finnish Forest Research Institute
		X	Hidaspyro	Development of slow pyrolysis business operations in Finland	VTT, Technical Research Centre of Finland
		X	HYPE	High efficiency consolidated bioprocess technology for lignocellulose ethanol	University of Helsinki
14	X		HYVOLUTION	Non-thermal production of pure hydrogen from biomass	
14			Icelandic ethanol oriented biorefinery	Icelandic ethanol oriented biorefinery	
	X		ICON	Industrial Crops producing added value Oils for Novel chemicals	SLU
		X	Improvement of Xylose Utilisation for Bioprocesses	Improvement of Xylose Utilisation for Bioprocesses	
		X	Industrial and agricultural sidestreams as raw material sources for new biomass products	Industrial and agricultural sidestreams as raw material sources for new biomass products	Biokasvu

	X		Industriell Bioteknik för produktion av plattform kemikalier	Industriell Bioteknik för produktion av plattform kemikalier	Perstorp
		X	Integrated utilisation chains of second generation pyrolysis	Integrated utilisation chains of second generation pyrolysis	VTT, Technical Research Centre of Finland
		X	JoBi	Risk mitigation and production flexibility in integrated forest biorefinery	
16			KACELLE	Kalundborg Cellulosic Ethannol Project	
		X	Kinetics of biomass pyrolysis (part of the project "Integrated utilisation chains of second generation pyrolysis")	Kinetics of biomass pyrolysis (part of the project "Integrated utilisation chains of second generation pyrolysis")	Tampere University of Technology
	X	X	LigniCarb	Lignin för kolfiberframställning	Innventia
		X	LigniVal	Lignin valorisation	VTT, Technical Research Centre of Finland
	X		LignoFuel	LignoFuel Program	Innventia
		X	LIPIDO	Optimizing Lipid Production by planktonic Algae	Finnish Environment Institute (SYKE)
		X	Microfuel	Microbes and algae for biodiesel production	
	X	X	NEMO	Novel high performance enzymes and micro-organisms for conversion of lignocellulosic biomass to ethanol	VTT, Technical Research Centre of Finland
	X	X	New, innovative pretreatment of Nordic wood for cost-effective fuel-ethanol production	New, innovative pretreatment of Nordic wood for cost-effective fuel-ethanol production	
13	X	X	NILE	New Improvements for Ligno-cellulosic Ethanol	
	X		Nya innovativa produkter från björkråvara	New innovative products from birch biomass	Innventia
		X	Optibio	Optimal use of NExBTL -diesel from renewable feedstock (phases 1&2)	
		X	Optimal Treatment Process of Lignocelluloses to Bioethanol	Optimal Treatment Process of Lignocelluloses to Bioethanol	
77			OSIRIS	OSIRIS	
		X	Oxygen-steam CFB gasification process development	Oxygen-steam CFB gasification process development	FW Energia Oy
		X	Pafrak	Fractionation and business potential from sludge	VTT, Technical Research Centre of Finland
		X	PEGRES	Paper, bioenergy and green chemicals from nonwood residues by a novel biorefinery	University of Oulu
23			PIIBE	Research aimed at supporting the Introduction of Biodiesel in Spain	
		X	Pilot plant for waste based ethanol production	Pilot plant for waste based ethanol production	UPM
		X	Poliols and biofuels	Poliols and biofuels	Finex
		X	Polysaccharide-based Biofuels and Smart Biomaterials: Sustanable Production Integrated with Pulp and Paper Processes	Polysaccharide-based Biofuels and Smart Biomaterials: Sustanable Production Integrated with Pulp and Paper Processes	
		X	PRE-CU	New methods applicable for biomass pre-treatment	VTT, Technical Research Centre of Finland
	X	X	Probark	A Sustainable process for production of green chemicals from softwood bark	VTT, Technical Research Centre of Finland
		X	Production of green diesel from algaes	Production of green diesel from algaes	
	X		PROETHANOL2G	Integration of Biology and Engineering into an Economical and Energy-Efficient 2G Bioethanol Biorefinery	
	X		PROFIT	Profitable bioenergy and paper production through innovative raw material handling and process integration	
		X	PROFOAM	Promoting functional biopolymer foams	VTT, Technical Research Centre of Finland
	X	X	PROSUITE	Development and application of standardized methodology for the PROspective SUstaInability assessment of TEchnologies	

		X	Protein and Organic Fertilizer	Protein and Organic Fertilizer	Finnamyl
12			PSE MICROALGAS	Production and valorisation of biomass from microalgae	
		X	PUUMA	Use of wood-based materials in rubber compounds (PUUMA)	Nokia Tyres
		X	Pyrolysis oil; preprocessing of raw material, quality assurance and combustion tests	Pyrolysis oil; preprocessing of raw material, quality assurance and combustion tests	Fortum
	X		RENEWAL	Improving plant cell walls for use as a renewable industrial feedstock	
		X	Replacement of chemical pesticides and biocides with birch distil	Replacement of chemical pesticides and biocides with birch distil	Charcoal Finland Oy
		X	Star-COLIBRI	Strategic Targets for 2020 - Collaboration Initiative on Biorefineries	
		X	SUBICHOE	Sustainability of Biomass Utilisation in Changing Operational Environment	VTT, Technical Research Centre of Finland
		X	SugarTech	Hydrolysis technology for producing sugars from biomass as raw material for the chemical industry	VTT, Technical Research Centre of Finland
	X		SUNLIBB	Sustainable Liquid Biofuels from Biomass Biorefining	
19	X		SUPRABIO	Sustainable products from economic processing of biomass in highly integrated biorefineries	
		X	SUSFUFLEX	New, innovative sustainable transportation fuels for mobile applications: from biocomponents to flexible liquid fuels	
		X	SusProc	Sustainable Processing of Natural Resources	
		X	SUSWOOD	Sustainable and Eco-Friendly Wood Material for Future Industrial Needs	
	X		Synergies for Improved Environmental Performance of First Generation Biofuels for Transportation	SYNERGIES FOR IMPROVED ENVIRONMENTAL PERFORMANCE OF FIRST GENERATION BIOFUELS FOR TRANSPORTATION	Linköping University(?)
		X	The effects of intensive bio-fuel production and use on regional air quality and global climate	The effects of intensive bio-fuel production and use on regional air quality and global climate	University of Helsinki
		X	TKK Biorefinery	CONCEPTS FOR SECOND GENERATION BIOREFINERY	Aalto University School of Science and Technology
		X	TORREFACTION	Torrefaction of agro and woody biomasses as energy carrier for European markets 2020	VTT, Technical Research Centre of Finland
		X	Transportation bioethanol from cellulosic and ligncellulosic waste material via St1 process	Transportation bioethanol from cellulosic and ligncellulosic waste material via St1 process	St1 Biofuels
		X	UCGFunda	Fundamental studies of synthetic-gas production based on fluidised-bed gasification of biomass	VTT, Technical Research Centre of Finland
		X	Upgrading Biogas for Vechicle Use	Upgrading Biogas for Vechicle Use	
		X	URAKAMU	Nouvel routes towards catalytic transformations of renewable biomaterials	Åbo Akademi University
		X	URAKAMU II	Catalytic valorization of renewable raw materials	
		X	ValueWaste	Value chains for biorefineries of wastes from food production and services	MTT, Agrifood Research Finland
15			YXY-Pilot Plant	YXY-Pilot Plant from Avantium	

Other research projects

Annex table 4. Selected project from the data base of Bioenergiatieto.fi: http://www.bioenergiatieto.fi

54	HighBio Interreg Nord 2008-2011	Refining of new products and new raw materials by gasification of biomass	Kokkola University Consortium Chydenuius/ University of Jyväskylä
55	HighBio2	Biomass to energy and chemicals	Kokkola University Consortium Chydenuius,/University of Jyväskylä

Source: Bioenergiatieto.fi: http://www.bioenergiatieto.fi Accessed: 25.6.2012