BIOENERGY
THE SWEDISH EXPERIENCE

How bioenergy became the largest energy source in Sweden

Kjell Andersson

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FOREWORD

Bioenergy is the leading energy source in Sweden today. The Swedish energy system has gone through a major transformation. In the 1970s oil was totally dominating. Today, oil is almost entirely a transport fuel, whereas bioenergy has taken over in district heating, and plays a major role in industry and in electricity production. People from around the world wonder how it all happened.

This book tells the story, and lists some of the factors that made the development possible. It also gives an up-dated picture of the role of bioenergy in Sweden today.

This is the second edition and the third printing. Diagrams and facts have been brought up to date, but the text is in general the same as in the first edition. We are thankful for questions and suggestions for future editions.

The text is produced by our communications director Kjell Andersson, and most of the pictures and diagrams are our own.

Gustav Melin, President Svebio

Stockholm, November 2015

CONTENT

MEASURING ENERGY

In this book we use Wh (often kWh and TWh) as standard units for all kinds of energy. The reason is that this is the usual practice in Sweden, and in the sources we have used for this book. Boiler capacities are usually expressed in kW or MW, and solid fuels are paid per MWh.

The international standard unit is joule (J, MJ, PJ, etc), always used by scientists. In the EU the standard is to use Wh for electricity but toe, tonnes of oil equivalents (or Mtoe) for fuels. The Americans use btu, British thermal units (or quads, quadrillions of btu). One can also use calories, and historically they used horsepower.

Here is a little table to help you convert units:

	PJ	TWh	Mtoe
PJ	1	0.28	0.02
TWh	3,6	1	0.086
Mtoe	41.9	11.63	1

How much is a TWh (Terawatt hour)?

One TWh is 86 000 toe (tonnes of oil equivalents), or the energy content in 100 000 cubic metres of oil. One cubic metre of crude oil contains very close to 10 MWh of energy.

One tonne of pellets holds 4.6 MWh of energy, which means that 1 TWh corresponds to 217 000 tonnes of wood pellets.

Sweden uses 400 TWh of energy in a year, or 42 MWh per inhabitant (9.5 million people).

A btu is 1,055 joule. Often large volumes of energy are presented in quads. 1 quad is 1 quadrillion btu, which means that 1 quad is a little more than 1 EJ (Exajoule) or 293 TWh. One could also say that 1 TWh is equivalent to 3.4 trillion btu.

INTRODUCTION

1.

◄ Sweden has rich natural resources, more forests than any other country in the EU. But also 100 000 lakes.

Photo: Lars-Erik Larsson

The use of bioenergy in Sweden has increased from 40 TWh/year in the 1970s to around 140 TWh today. In 2009, bioenergy surpassed oil as the leading energy source for the Swedish energy consumption. The same year, the total use of bioenergy was more than the use of electricity from hydropower and nuclear power together.

Biomass has a dominant position in the Swedish heat market, to a large part as fuel in district heating. Biomass is also the main energy source in energy intensive forest-based industries. Bio-electricity accounts for 7–9 percent of Sweden's power production, and biofuels are making inroads into transport fuels. Bioenergy is characterised by diversity, and by expansion in all markets.

Increased bioenergy use is the main reason that Sweden managed to decrease greenhouse gas emissions by 25 percent between 1990 and 2014, while GNP increased by 60 percent. Bioenergy use more than doubled during the period, see p.69.

The primary reason for the tremendous growth of the bioenergy sector in Sweden is broad political support and the use of strong general incentives like the Swedish carbon dioxide tax (introduced in 1991) the green electricity certificates (introduced in 2003), and tax exemption for biofuels for transport, as well as direct investment supports.

The bioenergy success story also rests on the long-standing Swedish tradition of using the natural resources in our forests, whilst simultaneously protecting and developing these resources. The total stock of wood in the Swedish forests, and stored carbon, has increased year by year, despite the rapidly increasing use of biomass for energy.

A brief history of Swedish bioenergy

Before the industrial revolution, biomass was the major energy resource in Sweden, providing firewood for heating of homes, wood and charcoal for iron production, and oats for horses, the leading power source in agriculture as well as for transport and warfare.

Hydropower for factories, mills and sawmills, and wind-power for mills were also important power sources.

With the industrial revolution, fossil fuels took over, first coal and coke, later petroleum, and, in Sweden to a very small extent, fossil gas. After World War II, oil was king, and around 1970 Sweden was 70–80 percent dependent on imported oil. This made sense at the time, because oil was extremely inexpensive during this period. Even in the Swedish countryside, in the midst of vast forests, farmers changed from firewood boilers to boilers using heating oil.

This was the situation when the oil crisis hit in the autumn of 1973, when OPEC raised the oil price, and the Arabic oil producing countries cut supply of oil as a political tool in the Middle East conflict.

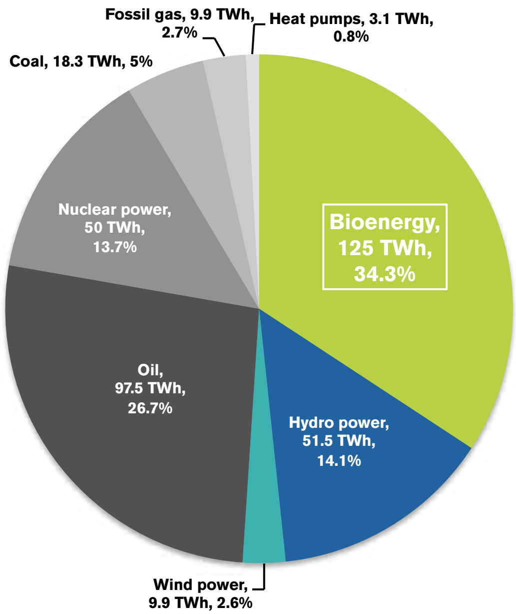
The world market price of oil increased drastically within days, and the Swedish government decided to impose rationing of oil products. To make matters worse, an unusually cold winter hit Sweden. In the same period, a fierce debate over nuclear power started in Sweden. Both the oil dependency and the nuclear debate led to a growing interest in alternative energy sources, from politicians, from media, from researchers, and from the public.

In 1979, two things happened that reinforced this focus on new energy resources. The second oil crisis was triggered by the fundamentalist take-over of the Iranian government led by Ayatollah Khomeini, cutting exports with rising oil prices as a result. In the spring of 1979 the nuclear accident at Three Mile Island in Pennsylvania brought new plans for nuclear power to a halt globally. The accident at Chernobyl a few years later underscored this development. In Sweden, the reaction to all these events was a growing focus on domestic energy resources, like peat and woodchips. Research into renewable energy sources was initiated in the late 1970s. A broad research programme also included wind energy and solar energy. Within bioenergy much interest was given to short rotation coppice production with willows, but also to different processes to efficiently use biomass from forests and peat from peatlands.

In 1980 Sweden held a referendum on nuclear power, and parliament decided to phase it out by 2010. Support for bioenergy was given by investment grants to convert boilers and heat plants from oil to other fuels, like peat and woodchips. At this first stage, support was also given to install coal boilers. The climate issue hadn't yet become a political factor.

The use of solid biofuels grew in the 1980s, but at a moderate pace, not least because oil prices declined during the decade. The situation changed dramatically in the 1990s, particularly in the heating sector. The reason for this development was the carbon tax, or rather "carbon dioxide tax" that was introduced in 1991, after a decision by the Swedish parliament in 1990. More about carbon tax on page 65.

The carbon tax made fossil fuels more expensive for the end user, and thus made renewable fuels more competitive. The carbon tax was set at a reduced



ENERGY USE IN SWEDEN 2014

Bioenergy is the leading energy source in Sweden today. Final energy use by source 2014.

Source: Svebio based on statistics from Swedish Energy Authority.

level for industries, but full tax was levied on domestic households and on the service sector. During the coming years the carbon tax was increased gradually and reached a level where it doubled the price of heating oil. Step by step oil was driven out of the heating market, both in heat plants and in boilers in single houses. Conversion from oil to biomass also took place in many industries.

The transformation in district heating was profound. At the end of the 1970s heating oil accounted for 90 percent of the fuel in district heat plants. By 2014, the share of fossil oil was only two percent of the total fuel use in district heating. Biomass had taken oil's place, growing from a couple of percent at the end of the 1970s to more than 70 percent in 2014.

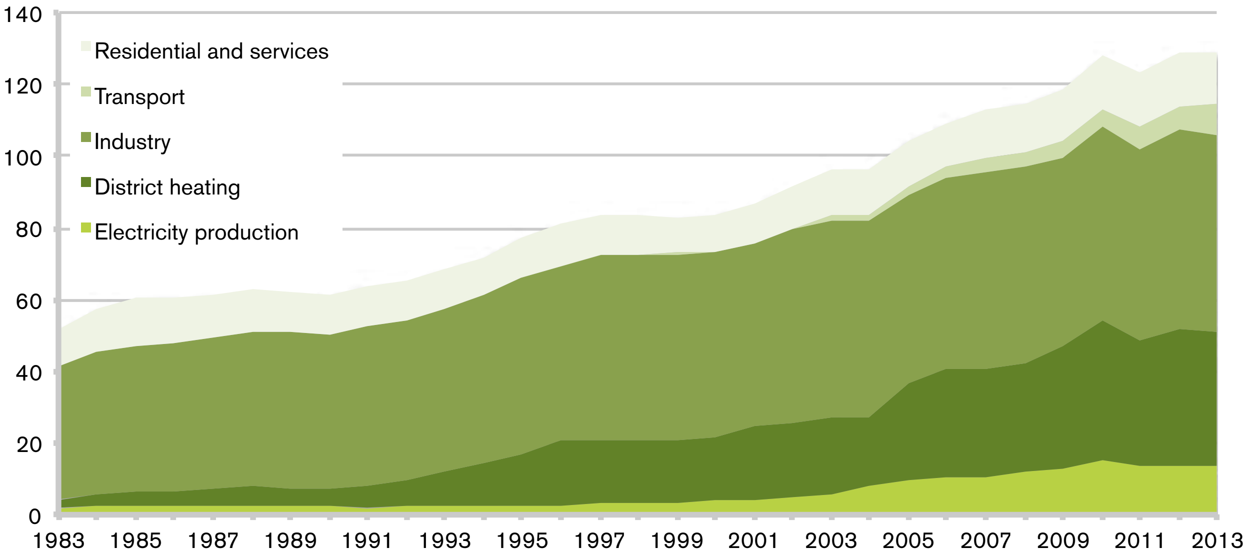
During the 1990s investment grants were given to new CHPs (combined heat and power plants) using biomass to produce bio-electricity. In 2003 a green certificate system was introduced to support investments in new power plants using renewable resources. This support scheme has led to rapid expansion of bio-electricity production.

When the first large ethanol plant was built in 2001, tax exemption was granted for the ethanol produced. This tax break led to a rapid introduction of liquid biofuels on the Swedish market for transport fuels, and Sweden became a leader in Europe in introducing biofuels for transport. Sweden also developed a market for high-blend biofuels – E85 and biogas.

USE OF BIOENERGY 1983–2013 (TWh)

The use of bioenergy in Sweden almost tripled in 30 years time, with growth in all sectors.

Source: Swedish Energy Agency.



BIOHEAT

2.

◄ The district heat plant in Vingåker is a typical smaller sized unit found throughout Sweden. Wood chips with up to 55 percent moisture content are used, sourced locally and supplied by tractor or truck. The wood chips are stored in piles outdoors on a paved surface and a wheeled loader is then used to fill the fuel bunker. The high tower is the hot water accumulator tank.

Photo: Alan Sherrard

Firewood is a major energy source for heating in Sweden. Of all 1.9 million single homes 650 000 use biomass (firewood, pellets or chips), often in combination with electric heating.

Photo: Kjell Andersson

Biomass for heating is the largest and most common bioenergy use in Sweden. Heat is needed for space heating in homes, public buildings, offices and industries, and for process heat in industries, for buildings on farms, for greenhouses, etc.

Bioheat today accounts for more than half of all space heating in the housing and service sectors, either through direct use in boilers, or indirectly through production of heat in heat plants and use as district heat. All kinds of biomass are used, but the predominant type is forest biomass – wood fuels from forestry and forest-based industries.

Firewood

Biomass has been used for heating since ancient times in Sweden, and firewood is still a major source of heat in hundreds of thousands of Swedish homes, primarily in the countryside and in smaller towns and villages, but also in the cities and suburbs. Conventional firewood heating with a boiler and hot water piping in the house is still the economically most favourable way of heating a house. Many Swedes have access to forests as forest owners, and can harvest their own firewood. Even if it is cheap to use firewood, it can be time-consuming, and it also requires the user's presence to feed the boiler. One way to make firewood heating less time-consuming and more efficient, and at the same time reduce local emissions, is to install a hot water accumulator to store energy. With a heating system with an accumulator the boiler only needs to be fired up once a day or once every other day. The accumulator can also be used to store heat from a solar panel. Combined systems using both firewood and solar collectors are becoming more and more common.

All kinds of wood can be used as firewood, but in general the foresters and forest owners utilise wood without industrial use, such as wood from thinning operations, and other marginal resources.

Some tree species have higher wood density and hence higher energy content than others. Birch is common in all parts of Sweden, and it is excellent as firewood. In southern Sweden, beech is a common tree, and it also has high energy value. Other tree species commonly used for firewood are alder, aspen, maple and willow. The common conifers, pine and spruce, are the main industrial tree species, but also much used for firewood.

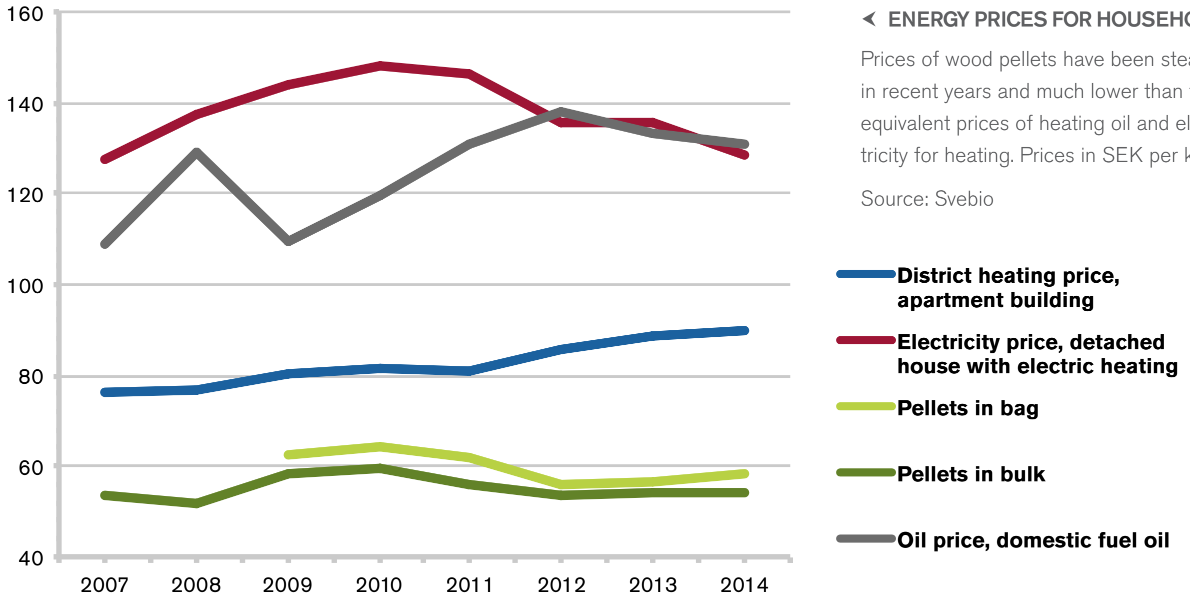
Small-scale heating with pellets

The first small scale pellet heaters were introduced on the Swedish market in 1988. The technology was American, but soon Swedish companies caught on and started producing Swedish pellet burners, boilers and ovens. Today there are around 100 000 small-scale pellet systems in operation.

Pellet heating is competitive compared to district heating, heat pumps and electric heating. Oil boilers have virtually disappeared from the domestic market, and very few oil boilers have been installed in recent years.

The main driving force for the introduction of heating with pellets has been the carbon tax, introduced in 1991. This tax has made heating oil increasingly expensive, and the tax has been raised in several steps since it was introduced. The government also briefly supported the shift from oil based heating and electric heating by providing investment grants to households converting to heating with pellets. This kind of support was also given for installations of heat pumps and solar heating.

The total use of pellets for small-scale heating was around 532 000 tonnes in 2014.



ENERGY PRICES FOR HOUSEHOLDS

Prices of wood pellets have been steady in recent years and much lower than the equivalent prices of heating oil and electricity for heating. Prices in SEK per kWh.

Source: Svebio

Biomass in district heating

In the late 1970s around 90 percent of district heating in Sweden was based on imported oil. Today more than 70 percent of the heat in district heating is derived from biofuels (including municipal waste and peat), and the use of oil has been reduced to only a couple of percent. In fact, bio-oil makes up a larger share than fossil oil in the fuel mix. Today, oil is almost exclusively used for peak load, start-up and as back-up fuel.

Pellets are used for heating in single homes but also in boilers for district heating.

Photo: Mikael Damkier

The use of biomass for district heating has grown from almost nothing in the 1970s to 40 TWh today. The main fuels are residues from forest-based industries (bark, sawdust, chips, shavings, etc), forest residues (tops, branches, wood of low industrial value), recovered waste wood, refined wood fuels (pellets and briquettes), municipal and industrial biogenic waste, bio-oils, and peat.

Furthermore there is also substantial use of waste heat from forest-based industries in nearby communities. This is not recorded as renewable energy use in the statistics, but several towns and cities get their district heat from paper and pulp factories, for example Varberg from the Värö pulp plant on the west coast.

District heating accounts for more than half of the heating of buildings in Sweden. The district heat grids were built after the World War II, with a strong expansion during the 1960s and 1970s. In the beginning, the reason for the large investments in this infrastructure was to reduce air emissions from thousands of individual furnaces and boilers, and instead build large heat plants with efficient flue gas cleaning. Thousands of chimneys in a city could be replaced by one single smokestack. The result was very positive. Air quality improved drastically in the cities, particularly in wintertime.

Swedish district heating is based on hot water under low pressure. The temperature is usually 90 °C.

Developments during the last 40 years

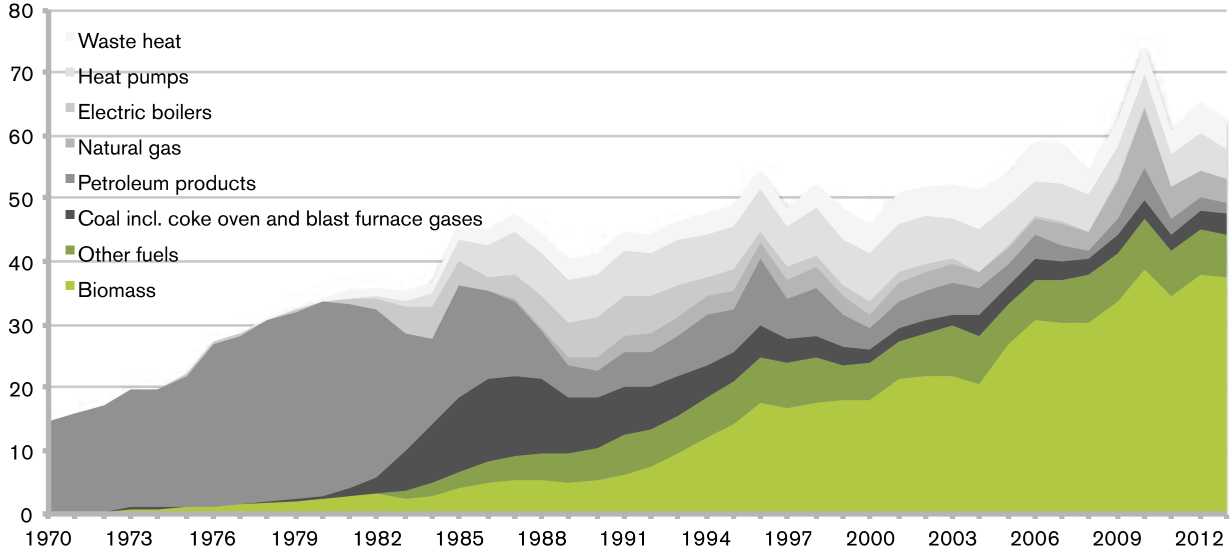
The growth of biomass use in district heating has been a major driving force in the development of the bioenergy market in Sweden. When the oil crisis hit in 1973, and again in 1979, the dependency of heating oil for district heating was seen as a major problem. The politicians introduced policies to convert oil boilers to other fuels. The first goal was “reduced dependency of oil”, the second one was “use of domestic fuels”. According to the first goal, coal was better than oil. Coal could be imported from other regions of the world rather than the politically sensitive Middle East. Coal was also less expensive and

Photo: Torbjörn Bergkvist

The city of Sundsvall in middle Sweden is located between two mountain ranges. Before district heating was introduced, smoke from hundreds of chimneys and smoke stacks caused serious air pollution, particularly on cold winter days.

Today almost all of the houses are connected to the district heating grid, supplying 80 000 people with heat. And the air quality has improved accordingly.

Pictures supplied by Sundsvall Energi.



ENERGY SUPPLIED TO DISTRICT HEATING, 1970–2013 (TWh)

During the previous 30 years, biomass has taken over as fuel in Swedish district heating. Fossil fuels dominated in the 1980s, but today bioenergy and "other fuels" (peat and waste) account for 75 percent of consumed fuels.

Source: Swedish Energy Agency and Statistics Sweden.

the prices were less volatile. The global warming issue was not yet on the political agenda. A number of oil plants were converted to coal, and a number of new coal fired heat plants were built.

At the same time there was a growing interest in domestic fuels. Peat had been used extensively during World War I as well as during World War II to substitute coal and oil when the import of these fuels was cut off by the war activities. The Swedish peat resources are very large. At the time, a state owned company still produced horticultural peat, and possessed the knowledge for peat extraction.

The use of wood chips for heat plants was promoted both by a number of public utilities and by a few forest companies, first and foremost the forest owners co-operatives.

Among the first heat plants built for wood chips were the plants in Mora in middle Sweden in 1978 and in Enköping west of Stockholm in 1979. They were soon to be followed by many others. The development was stimulated with governmental investment grants. The first large conversion of a heat and power plant (CHP) took place in Växjö in southern Sweden in1980.

The introduction of the carbon dioxide tax in 1991 made biomass more competitive across the board. During the 1980s the oil price had declined which once again made fossil fuels competitive, and put pressure on the plants that had converted to domestic fuels. With the carbon taxation the biomass market received a new push, but the prices on solid biofuels were still very low.

However, the bioenergy movement also met resistance, especially from the pulp and paper industry. The worries focused on the competition of raw material. The pulp and paper industry, through lobbying activities, succeeded in getting legal protection for “raw material suitable for industrial processes” in the “Wood fibre law” of 1987. This law was in force only for a couple of years, until 1991, for most wood materials, but until 1993 for sawdust and shavings, to protect the panel board industry. The law had an influence on the opinion that biomass for energy should emanate from “non-industrial” sources such as tops, branches, decayed wood, etc.

An important factor in favour of bioenergy was the very fast increase in efficiency and the decrease in prices of biomass fuels.

Notwithstanding these tumultuous conditions, new heat plants were built all around the country, and many of the old ones were converted to biomass. A support scheme for biomass CHPs gave a further boost in the 1990s, and a number of large plants were built. By the end of the century almost every major town and city had a heat plant or CHP using domestic fuels.

Among the larger projects was Uppsala, Sweden’s fourth largest city. The public utility, Uppsala Energi, decided to use peat, and started a peat briquette production in Sveg in the mountain region in 1990. The peat was loaded on trains and taken to Uppsala. The project created many new jobs in the Sveg area, and is a good example of how the target “security of supply” was implemented on a local level. The alternative in this case would have been to import coal from overseas.

Today there are close to 500 heat plants using biomass fuels, all over Sweden, including plants delivering more than 2 GWh heat per year. Of the 290 Swedish municipalities all but a handful have district heating, and many have several grids.

Modern insulated pipes make it possible to connect large areas to a common heat grid. Here a new pipe is laid in a street in Stockholm.

Photo: Kjell Andersson

Can district heating expand?

Almost all cities and towns have district heating today, and the vast majority use biomass. A number of large plants use municipal waste, and some use peat. Can the use of district heating be developed further, or is the market saturated?

This small heat plant supplies the town of Gränna with heat and hot water. The plant uses wood chips and was built by Hotab.

Photo: Kjell Andersson

There are many buildings not yet connected to the district heating grids. Most apartments buildings are on the grids, but only about 10 percent of the detached family homes. Also, many industries still use heating oil or other fossil fuels, and could convert to district heating.

A second possibility is to build district heating in small towns and villages where heat grids do not yet exist.

One development that will decrease the demand of heat is energy efficiency measures in buildings. Many apartment buildings will be refurbished in the coming decades.

Small-scale heat plants

In smaller towns and villages, local entrepreneurs, farmers or forest owners, as well as public utilities and energy companies have engaged in setting up small heat plants. Many of these small heat plants are not recorded in the statistics above. The smaller heat plants delivering less than 2 GWh, probably, to date, number several hundred, but they have not been listed in the statistics, and setting up a local heat grid does not require any permit. In fact, district heating is not highly regulated in Sweden. It is a matter between the heat producer and the heat consumers, and the legislation surrounding the necessary infrastructure is favourable to the investors.

Permits are granted by the municipalities for smaller boilers, and by the province administrations (länsstyrelsen) and the environmental courts for larger boilers and heat plants, to guarantee compliance with environmental laws. Boilers under 500 kW installed in the countryside do not require a permit.

A typical small local heat grid will include a boiler using wood chips, pellets, or straw, and a hot water grid connecting the boiler to the school, the church, a few apartment buildings or small industries, and may also deliver heat to some of the family homes in the locality. Often the municipality and the parish own some of these buildings and want to reduce the cost for heating, thus relying on locally produced heat. In many cases running the heat plant is an extra income for a local farmer.

Some companies have also specialised in delivering “ready heat” (färdig värme), where they own and run a boiler and deliver the heat to an industry, a hotel, a community or a few houses.

BIOENERGY IN INDUSTRY

3.

◂ Holmen Paperboard in Iggesund reduced its emissions of fossil carbon dioxide by 90 percent between 2005 and 2014, primarily by using the company's own biomass residues for the energy needs of the plant.

Photo: Kjell Andersson

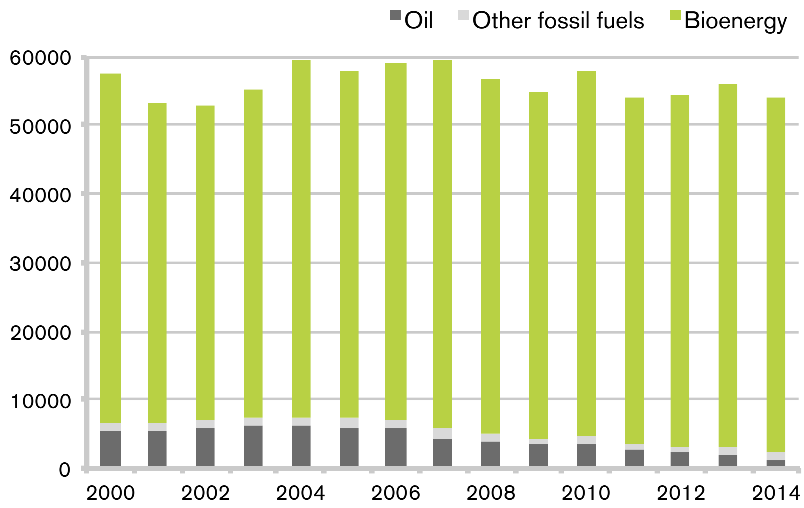
Bark is a major biomass resource at pulp mills and saw mills. Fresh bark has an energy value of 1.6 MWh per tonne.

Photo: Kjell Andersson

Biomass and electricity are the two main energy sources for Swedish industry, each supplying around 50 TWh. Whereas electricity is used in all types of industries, biomass is traditionally used primarily in forest-based industries: in pulp and paper mills, in saw mills, and in other types of wood working industry. The pulp industry is by far the largest energy user in Swedish industry, which explains why biomass is such an important energy source for the industrial sector as a whole.

The biomass used in forest-based industries is almost entirely made up of by-products and residues produced at the mills.

- Pulp mills use black liquor in great quantities for their recovery boilers. The black liquor contains all the components of the wood that are not cellulosic fibre, which makes up the pulp. A major component is lignin. The use of black liquor in the pulp industry amounts to 40 TWh yearly, one tenth of Sweden's total energy consumption!
- From the black liquor, one can extract tall oil, which can be used to produce biodiesel, be burnt as a substitute for fossil oil, or be used as a raw-material for a number of chemical products.
- Besides black liquor, the pulp mills also use bark and sawdust for their boilers, producing enough electricity to meet most their own demand. A number of pulp mills meet their entire demand for electricity, and some even produce a surplus they can sell to the grid. Värö bruk, owned by Södra and located south of Gothenburg, was the first mill to reach power self-sufficiency in 2009.
- Paper mills also use residues from their own production, but often have a large need for electricity for their paper machines, which they have to buy. Often, pulp and paper mills are integrated, and can optimise the use of energy in combined systems. Excess heat from pulp production can, for example, be used for drying and other processes in the paper mill.
- Sawmills produce large quantities of residues. About half of a log becomes planks, and the rest will be by-products or residues, which can be used for energy purposes. Some of the clean wood residues are chipped and taken to pulp mills. The sawdust is usually used for pellets production or sold to heat plants. Bark is used as fuel, usually in a boiler at the sawmill for drying of the sawn wood, or sold to heat plants.
- Other kinds of wood-working industries, like the furniture industry and producers of modular houses, produce dry wood residues, like scrap wood and shavings. These residues are often used on site for internal energy needs, or used for pellets production.



ENERGY USE IN SWEDISH FOREST-BASED INDUSTRIES (GWh)

The total use of bioenergy in forest-based industries is more than 50 TWh. The use of fossil fuels, mainly heating oil, has decreased by 71 percent in the last ten years. Forest-based industries include pulp and paper mills, sawmills and woodworking industry.

Source: Statistics Sweden/Svebio

- Despite this substantial use of bioenergy in forest-based industries, these companies have also used some fossil fuels, e g. for lime kilns. In recent years, the use of fossil fuel has been reduced drastically, by more than 70 percent between 2004 and 2014.
- One major driving force for the increased use of biomass and the reduced use of fossil fuels is green certificates, introduced in 2003. These certificates have made it very profitable for forest-based companies to produce bioelectricity with their own turbines, for their own needs and even for sale to the power market.

A modern sawmill produces large volumes of residues. Most is used at the site, but large volumes are also sold to heat plants and pellets factories.

Photo: Kjell Andersson

Biomass in other industries

When the carbon dioxide tax was introduced in the early 1990s, the tax rate for industries was reduced in relation to the full carbon tax paid by households and the service sector. When emissions trading was introduced in 2005, industries in the EU Emission Trading System (ETS) were exempt from carbon tax, but other industries still had a reduced carbon tax. In recent years, between 2011 and 2016, this tax reduction has been drastically reduced and will be taken away entirely in 2018. After this date, any industries outside ETS will have to pay full carbon dioxide tax, just like enterprises in the service sector.

Tall oil is a sticky oil extracted at pulp industries. A few percent of the wood in pines and spruces are resins that end up as tall oil.

Photo: Chemrec

Alverbäcks outside Stockholm is a leading producer of tulips for the Swedish market. The company uses woodchips to heat the greenhouses.

Photo: Rebecka Ramstedt

This change has triggered broad introduction of bioenergy solutions in the industries concerned, and we have seen a large number of projects for conversion from fossil fuels to low-carbon solutions using woodchips, pellets, bio-oils and district heating (hot water or steam). Here are some examples:

» Dairies
» Breweries
» Asphalt preparation
» Laundries

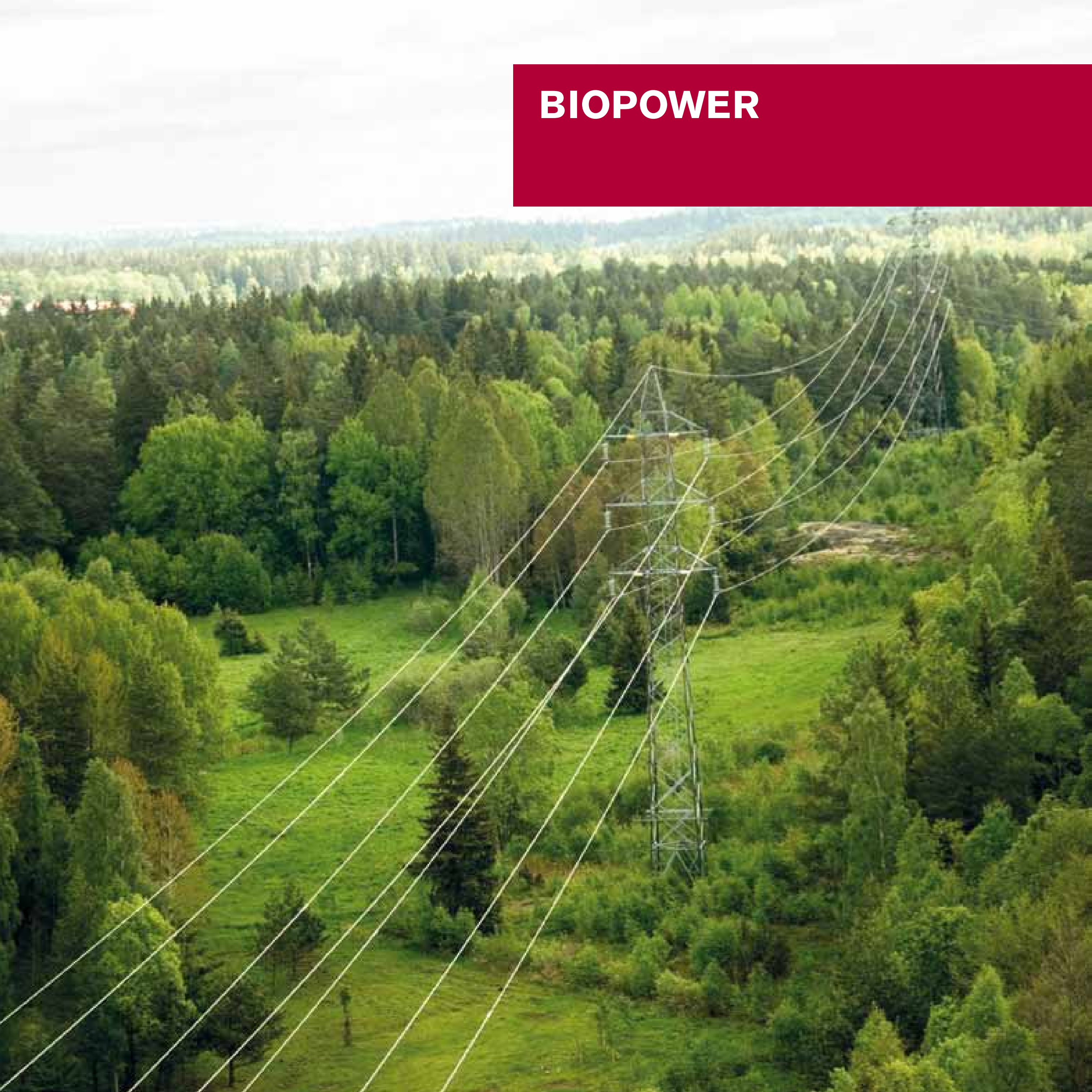
Among other fore-runners are slaughterhouses connected to district heating, fossil-free bakeries, fossil fuel free Volvo plants, etc. There are several examples of factories using pellets, such as a candle factory, a vegetable oil company using pellets, a candy maker, a zink mine, and many more.

Biomass use in greenhouses and agriculture

Between 2001 and 2011, the use of energy per square metre in Swedish greenhouses decreased by 42 percent. The use of fossil fuels, mainly heating oil and natural gas, decreased from 77 percent of the energy use to 43 percent, and the use of biomass increased from 5 percent to 37 percent. We lack more recent statistics, but today biomass is undoubtedly the leading energy source of energy in greenhouses in Sweden.

In agriculture, the use of diesel is still predominant, but in Östergötland, one of the leading agricultural provinces, a successful project to demonstrate fossil-free agriculture, using biofuels for tractors, machinery, dryers and transport, is under way.

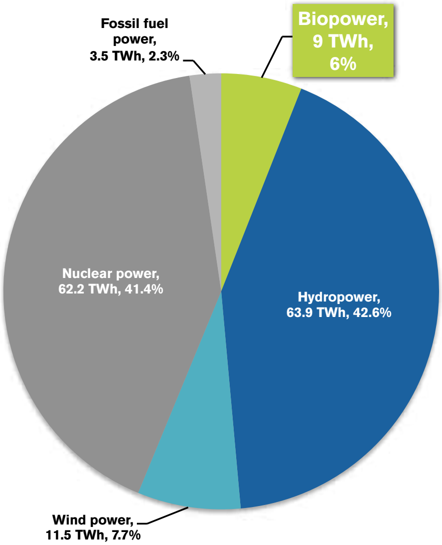
BIOPOWER



4.

◀ Swedes use a lot of electricity. One reason is the abundant supply of hydropower in northern Sweden. Today, renewable electricity also comes from wind-power and biopower.

Photo: Svenska Kraftnät, Håkan Flank



ELECTRICITY PRODUCTION 2014

Biopower was the fourth largest source of electricity in Sweden 2014, trailing hydropower, nuclear power and wind power. Half of the biopower is produced in CHPs in district heating, half in generators in the paper and pulp industries.

Biomass based electricity today accounts for 7–9 percent of Sweden's electricity production. Almost all of this biopower is produced by combined heat and power (CHP) installations in district heating and in forest-based industries. During recent years the production has levelled out, as a result of low electricity prices and over-capacity in Swedish power production. There is capacity to increase biopower production in the existing units as well as with new plants.

There are some 90 CHPs run by district heating utilities, producing 6.5 TWh of electricity. Most of these use wood fuels, but a number also use municipal waste, and a few use peat. A number of new CHPs are under construction.

In forest-based industries and a few other industries, 40 plants have biopower production. The largest units are located in the pulp plants. The yearly production is around 6 TWh. There are also 70 biogas units producing electricity.

How it came about

Investments in biopower production in district heating plants started in the late 1980s. There were already a number of CHPs using oil or coal at the time, but electricity production in CHPs was not promoted in general, as Sweden had a surplus of electricity, due to the expansion of nuclear power production in the 70s and 80s. Moreover, instead of producing electricity based on district heating, the heating utilities were, in fact, consumers of electricity, using surplus electricity in electric boilers and for large-scale heatpumps, to supply heat for the grids.

As a result of the nuclear referendum in 1980 the Swedish parliament decided to phase out nuclear power by 2010. To make this possible a number of programs were introduced to increase energy efficiency to cut the use of electricity, and to stimulate renewable energy growth. The strategy was to close down nuclear power production when it could be substituted by renewable electricity production or reduced electricity use. Eventually, two of the twelve Swedish reactors were closed down, Barsebäck 1 in 1999 and Barsebäck 2 in 2005.

As a part of this policy a support program for biopower production was introduced in 1991, with the purpose to build a number of CHPs using biomass, and producing 1 TWh of bioelectricity. The utilities and industries building the plants could get an investment grant of 30 percent of the cost. A number of CHPs were built during the 1990s. In 1997 this program was extended and more money was allocated.

The green certificates

In 1995 Sweden joined the EU, and in 2001 the EU passed a directive to stimulate the supply of renewable electricity (2001/77/EC). With this directive Sweden had a new motive to stimulate investments in renewable electricity production, beside the nuclear dismantling program. According to the directive Sweden was supposed to increase the share of renewable electricity to 60 percent by 2010, from 49.1 percent in 1997.

To reach this goal and to accelerate the investments in renewable electricity production the green electricity certificates were introduced in 2003, replacing the investment grants. The launch of this reform was preceded by a public investigation and different support schemes were considered. Many preferred a feed-in tariff system. However, the certificate system was chosen because it was a market-oriented system that would favour investments in the least costly technologies – using first the "low-hanging fruits", supposedly to the lowest cost for the consumers.

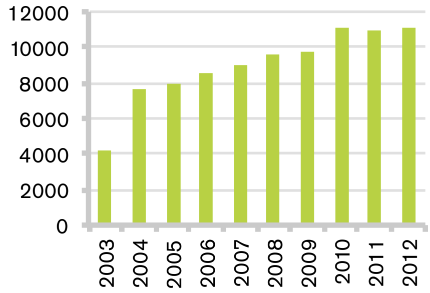
A downside of the system is that it will work both as a stimulus and as a brake on development, as it heads for a fixed production target. If the investments do not keep up with the target, the price of the certificates will increase, which will stimulate investment, and be positive for investors. But the opposite will happen if the investments and new production increases faster than the target. The certificate prices will fall, and new investments will be stalled.

When the system was introduced in 2003 existing installations with bio-electricity, wind-power and small-scale hydropower were included. Many of the CHPs and forest-based industries that used both biomass and fossil fuels in their production had, for tax reasons, reported and allocated their use of fossil fuels for electricity production. Now it was much more favourable to use biomass, and many units switched from fossil fuels to biomass right away, to qualify for the certificates.

Many new projects for biopower production also emerged. During the first years of the green certificate system expansion of biopower totally dominated the system, out-numbering wind-power four to one. Eventually wind-power picked up, and today these technologies are growing at about the same speed.

The most obvious "low-hanging fruits" were found in the forest-based industry. Several companies installed new generators and reduced the use of oil and coal and increased the use of wood fuels like bark, chips and sawdust.

BIO-ELECTRICITY PRODUCTION (GWh)



The production of bio-electricity receiving green certificates. After 2012 more than half of the production was phased out of the support system, and the statistics are since then uncertain.

Source: Swedish Energy Agency

How the certificate system works

All producers of certain categories of renewable energy production are awarded certificates in relation to their electricity production. Each MWh qualifies for one certificate. Existing large-scale hydropower does not qualify, but small-scale hydropower does. Biopower and wind-power are the other major categories. Power produced from peat also qualifies. Solar electricity qualifies, but the volume so far has been very small.

The certificates are freely traded on the market. They are bought by companies that distribute and sell electricity to consumers, at a certain quota. All electricity distributors have to have a certain share of certified electricity each year, and this share increases year by year. The demand for more certificates is driving the market and the certificate prices, thus stimulating investment in new renewable production capacity. Not all electricity use is included in the consumption that is the basis for the quota. Large-scale electricity use in energy intensive industry is excluded. Therefore the quota is based on 95 TWh out of the total consumption of 145 TWh.

Meva is a Swedish company developing small-scale electricity production from biomass, using gasification technology. A plant with 1 MW capacity was built in Hortlax in northern Sweden.

Photo: Meva

Development so far

From 2002 to 2010 the production of biopower increased from 3.5 to 13 TWh (of which 1.2 TWh was electricity produced from municipal waste which does not qualify for green certificates, and 0.7 TWh from peat, which does qualify). After 2010 production has levelled out, mainly due to low electricity prices, but also due to mild winters.

Swedish electricity production is about 60 percent renewable, with hydropower the main power source. Wind power has increased fast in later years, and the production capacity from wind and biopower are now in the same range. In 2015 the power companies Vattenfall and E.ON decided to close down four nuclear reactors before 2020. As the green certificate scheme will continue to promote more new renewable power production, the share of renewables in power production will increase even more in the coming years.

Combined heat and power

All Swedish biopower units are CHPs producing both heat and power. None of the units are condensing plants designed only to produce electricity. In a CHP the cooling water is used as heat and sold over the district heating grid.

With an absorption heat pump the energy can also be used for cooling in the summer. The total energy efficiency of such a plant is more than 90 percent. The energy losses in the district heating grid area is typically around 10 percent in a normal size grid in a Swedish city.

The share of electricity of the total energy production in a CHP using biomass can be one third, and the heat production consequently is two thirds. CHP technology is a prerequisite for efficient use of the biomass for biopower production. In the forest-based industry and in other industries the cooling heat from the power production is used in the industrial processes, e.g. for digesting the pulpwood and for drying.

The Igelsta CHP in Södertälje just south of Stockholm is Sweden's largest CHP using wood chips. The plant produces 550 GWh electricity per year.

Photo: Jann Lipka

In most other countries the normal way of producing electricity from fuels is in condensing plants, where the cooling energy is not used for heating or industrial processes. If all condensing plants in the EU were turned into CHPs and the cooling water was used for heating, this would suffice for most of the heating in the concerned member states.

The technology used in the plants is a conventional steam cycle technology improved in different ways to maximise the energy efficiency and reduce the energy losses through flue gases. One such technology is flue gas condensation, a technology that enables the plants to use biomass with relatively high moisture content and still maintain very high energy efficiency.

Much attention has also been given to flue gas cleaning, and substituting thousands of individual small boilers using fuels like heating oil, coke and firewood, with efficient and clean heat and power plants. These, coupled with district heating, have drastically improved air quality in the Swedish cities during the last fifty years.

High capital costs

The energy content per tonne of solid biofuels is about half of the energy content of coal or heating oil per tonne. Untreated “green” biomass also contains a lot of moisture. A result of this is that a biomass boiler has to have a much larger volume for the equivalent energy output compared to a coal or oil boiler. In addition, the flue gas cleaning is expensive – this is particularly true for waste boilers. Economically this means that biopower plants have a higher capital cost per produced kilowatt hour (kWh), compared to fossil fuel plants. Accordingly, the price of biomass fuels for biopower must be lower, or needs some kind of financial support to balance the extra investment cost. In Sweden, the solution has been the green certificates, which give a higher price for the produced biopower during the plants initial 15 years of power production. So far, the certificates have added 50–100 percent to the price compared with the market price.

Advantages with biopower

Biopower has a number of advantages, besides the obvious one, that it is renewable:

» Biopower is produced in the high demand season, from autumn to spring. In Sweden a substantial amount of electricity is used for heating purposes, and therefore electricity comsumption is lower in the summer. Furthermore, industrial consumption of electricity is lower in the summer season when many plants close for vacation periods and maintenance. Biopower in CHPs in district heating produce most during the period October–April. A result of this production pattern is that the producers can get a good price for biopower and that the production helps to cut costs for consumers.

» Biopower is produced near the consumers, and thus causes relatively low distribution losses. CHP plants are located in the larger cities and towns, and the biopower units in industry are located at plants using significant amounts of energy.

The biomass CHP in Enköping delivers 50 percent of the city's electricity and heat to most of its inhabitants.

» Biopower is produced continuously and not intermittently (like wind-power and solar power), and therefore reliable. It does not require balancing production units. On the other hand it cannot be used to balance wind-power. Large biomass CHPs are base-load units.

» Biopower plants can use a large number of fuels and for this reason biopower is a flexible energy source. Most of these fuels are waste or by-products of low cost that have no other use.

» Biopower uses well-established technologies and the risk for plant shut-downs is small. There is no risk for shut-downs for safety reasons, as with nuclear power. Also in this respect biopower can be deemed reliable.

» Biopower production is decentralised and the power is produced in a large number of middle-size and small units. This guarantees high access and low risk for power-shortage. Compared to nuclear power this is a big advantage. Shut-down of one or two large nuclear units can create shortage on the market if it occurs at peak-load time.

Can biopower grow in the future?

A recent investigation shows that there are plans for about 4–5 TWh expanded biopower production – 1 TWh in forest-based industry and the remainder in district heating. This expansion will be conducted via conventional installations – new generators installed in industries and new CHPs built by utilities and power companies. At the same time, some old installations will lose their green certificates as the support only covers the first 15 years of production, and some of these units will be used only for back-up. The total production of biopower will grow from 12 to 15 TWh under normal weather conditions. What will happen in the longer run? What is the total potential?

These are some of the possibilities to increase the production of biopower:

» There is still heat load in district heating that is not used as a basis for electricity production. Much of this exists in the Stockholm region, and several new CHPs have been proposed. The world's largest CHP is now under construction in Stockholm by Fortum.

» The heat grids and the total use of district heating can still be increased in many cities, by attaching industries and single homes to the grids. At the same time, the total heat demand may go down due to more efficient use of the heat, particularly in new and refurbished buildings.

» There are a few relatively large heat and power plants that still use fossil fuels, in Stockholm (coal), Gothenburg (natural gas), and Malmö (natural gas). These plants can be converted to biomass and/or biogas.

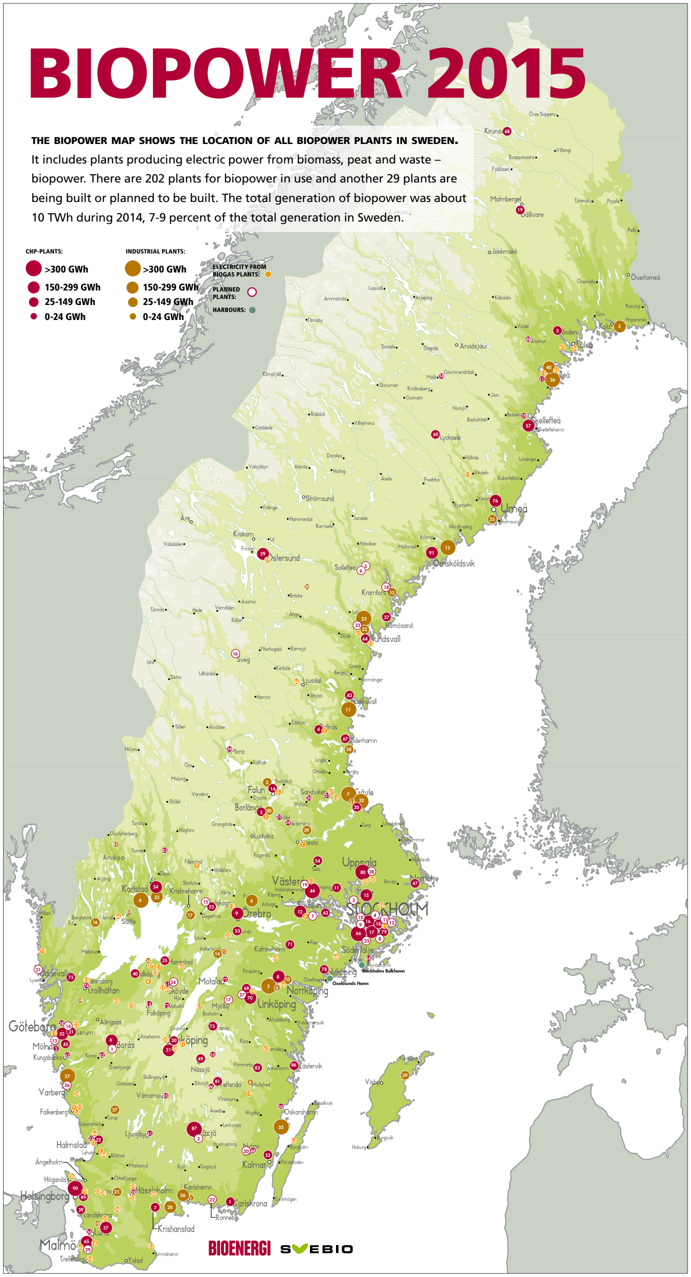
» The existing CHPs can be used more efficiently by extending their running times, especially during spring and autumn.

» Heat grids can be merged in many regions by building hot water pipes between towns and cities. Small heat plants can be shut down and the new larger plants supplying several towns will be large enough to motivate electricity production.

» The technology for small-scale electricity production may develop and make it profitable to produce electricity also in small plants. Several technologies have been considered, such as gasification, Stirling engines, and ORC (Organic Ranking Cycle), but we are still awaiting break-through for one or several of these technologies to make them economically feasible at the current price and support levels.

Most middle size cities now have combined heat and power plants (CHP) using biomass. This is the plant in Katrineholm west of Stockholm.

Photo: Kjell Andersson



» Another possibility is to increase the electricity output from a given amount of fuel. The engineers use the term "alpha value", which is the relation between electricity output and heat output. If the alpha value is 1, the plant produces 1 MWh of electricity for each MWh of heat. A typical high-efficient biomass CHP may have an alpha value of 0.5, producing 0.5 MWh of electricity for each MWh of heat. The output from the plant will be one third electricity and two thirds heat. If the alpha value can be increased to 0.75 the plant would produce 50 percent more electricity based on the same heatload. Improving the technology would drastically increase the potential for electricity production in the district heating systems. One way to do this would be to gasify the biomass before the final combustion and electricity production. This way the biomass CHPs could reach an efficiency comparable to the efficiency of natural gas plants. The capital cost of such a gasification plant would be relatively high.

There are several existing research and development projects on thermal gasification. One central question is if the produced gas should be used for power production or as transport fuel.

◂ BIOPOWER PRODUCTION UNITS 2015

Every year Svebio produces a map of all bio-power production units in Sweden. The map from 2015 shows biopower production at 202 locations, and another 29 planned units. This included 91 CHP plants in district heating, 41 units in industries, and 70 small plants using biogas for electricity.

The map is available for download on www.svebio.se. It is also possible to order printed copies.

BIOFUELS FOR TRANSPORT

5.

◄ There are more than 200 000 flexifuel cars on the Swedish roads. They can run on E85, a fuel with 85 percent ethanol and 15 percent petrol.

The road transports are still almost totally dependant on fossil fuels like petrol and diesel. Sweden has been at the forefront in Europe in working to reduce this dependency. This was done by an early introduction of low-blend of ethanol in petrol and by the introduction of E85 and flexifuel vehicles.

In 1983 the city of Örnsköldsvik was the first to introduce ethanol buses – two of them. A few years later the Stockholm Transport Authority (SL) bought 32 ethanol buses from Scania. This was the start of Sweden's ethanol story. The ethanol was furnished by a pulp factory that produced ethanol from a by-product. Around the same time a small ethanol plant was also built in Lidköping in western Sweden using grain as the raw material. Ethanol from this factory was mixed in with petrol in the Stockholm region by OK, the co-operative oil distributor owned by motorists.

The first large ethanol plant

The first large ethanol plant using grain as a raw material was built in Norrköping in 2001. The investor and owner of the plant was, and still is Lantmännen, the large farmer-owned co-operative company that handles much of Sweden's trade in grain, and supply of farm equipment. Behind the investment in the ethanol plant was not only a wish to produce a renewable fuel and use surplus land and grain, but also a hope that ethanol production would in the long run raise the price of grain for the farmers.

The ethanol plant in Norrköping is Sweden's largest biofuel industry.

Photo: Anders Haaker

Sweden has had a large surplus of agricultural products, much in the same way as the whole European region. One way of handling this surplus was to change the support schemes and pay less for the produce and more for environmental services and keeping farmland arable. Several hundred thousand hectares were set aside as fallow. Building the ethanol plant was a way of using some of this set-aside land for new production.

The original plant in Norrköping produced 45 000 cubic metres of ethanol per year – a rather small plant by international standards. In 2009 production was extended to 200 000 cubic metres. The plant is located near a large CHP run by E.ON, that produces heat for the city of Norrköping, using biomass as the energy source. The CHP also sells steam to the ethanol plant for the processes. The CHP and the ethanol plant can be seen as a combined bio-refinery. Some of the by-products from the ethanol plant are also used for biogas production, and the distiller's grain is sold as feed stuff. The last addition to the bio-refinery in Norrköping is a gas plant producing "green CO_2", to substitute carbon dioxide for industrial purposes, otherwise produced from fossil gas.

The ethanol from Norrköping was entirely used for low-blend in the regular petrol. This low-blend programme was introduced in east middle Sweden and gradually expanded to other parts of the country.

Introduction of flexifuel vehicles and E85

Public procurement was an intrinsic part of the development during the following years. Between 1998 and 2000 the city of Stockholm and other municipalities and public companies put out bids among car manufacturers to buy 3 000 flexifuel cars. Ford accepted the challenge, and this became the start of the Swedish flexi-fuel programme. During the coming years, Ford Focus Flexifuel became the leading brand for flexifuel cars, and tens of thousands of these cars were sold. At the end of 2013 almost 230 000 flexifuel cars rolled on Swedish roads – 228 679 vehicles to be exact.

Building a market for a new fuel is as "chicken-and-the-egg"-issue. You need both vehicles, and a reliable supply of fuel, at the same time. Without the one, the other cannot be sustained. Therefore, when the first flexifuel-cars were put on the market, there also had to be a reasonable amount of E85 pumps offering the fuel. A couple of the Swedish oil and petrol distributors stepped in and shouldered the cost and risk of building this new market. OK-Q8 was first, and followed by Statoil. Without the strong support of these companies the speedy development of the E85 market would not have been possible.

Promotion of environmentally friendly cars

After the introduction of flexifuel cars by procurement, a number of other measures were taken to promote environmentally friendly cars. There was also a constant debate over what cars would qualify for this label and thus be eligible for supports and favours.

From the start flexifuel cars that could be driven by ethanol made up the majority. Early on, bi-fuel cars that could use biogas were also introduced and given status as environmentally friendly cars. The bi-fuel cars can use either petrol or gas, and the gas may be natural gas or biogas or any mix of the two. The intention with these cars is to use as much biogas as possible, but the supply of biogas has, at times, been limited, and there has not been enough biogas pumps to guarantee use of biogas.

The third category included in environmental friendly cars were hybrid cars – Toyota Prius being the forerunner.

Agroetanol in Norrköping uses wheat as raw material. Sweden has several hundred thousand hectares of surplus farmland that can be used for energy crops.

Photo: Kjell Andersson

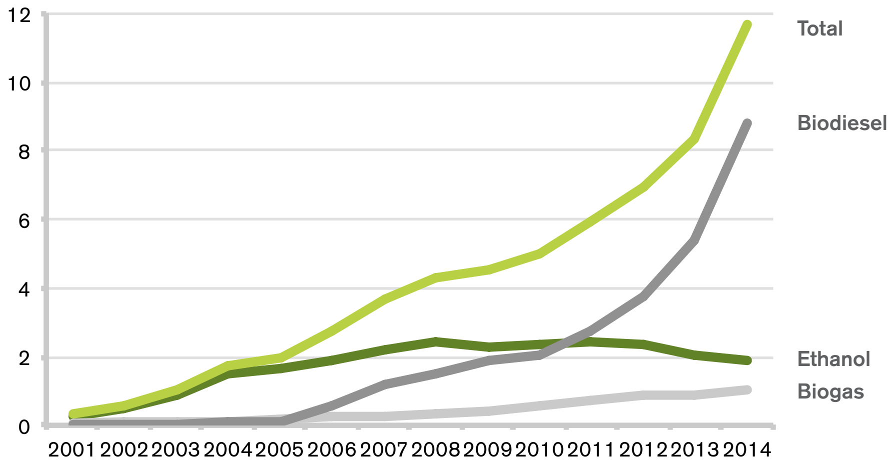
Lantmännen Agroetanol's plant in Norrköping produces around 200 000 tonnes per year of protein feed and the same amount of ethanol.

Photo: Kjell Andersson

USE OF BIOFUELS FOR TRANSPORT, 2001–2014 (TWh)

The use of biofuels for transport in Sweden has increased steadily since 2001. Together with renewable electricity for railroads, renewable fuels had reached the 10 percent EU target for 2020 during 2012, eight years ahead of time.

Source: Swedish Energy Agency



Eventually the politicians and regulators decided to also include highly efficient fossil fuel vehicles in the definition of environmentally friendly cars. The argument was that these cars, seen in a life cycle perspective, caused as little or less greenhouse gas emissions as cars using biofuels, when considering that flexifuel and bi-fuel cars were, on average, to a large share using petrol.

Therefore, an ever larger share of the environmentally friendly cars became efficient diesels – cars that were one hundred percent using fossil fuels!

Measures to promote environmentally friendly cars included the following:

» Free parking for environmentally friendly cars. This was a popular measure in larger cities where parking costs are high.

» Lower tax rates for environmentally friendly company cars. Users of company cars have to pay tax for the benefit of using these cars privately. This benefit was reduced for environmental friendly cars, which increased the interest in using these cars as company cars. It was a major reason for the large sales of the more expensive flexifuel cars produced by Saab and Volvo. Saab launched its Saab BioPower in 2005.

» Exemption from congestion fees in Stockholm. These fees were introduced as a trial in 2006, and made permanent in 2007. The purpose was to curb traffic into the city at rush hours thus decreasing traffic congestion.

- Sales premiums for environmentally friendly cars. A direct subsidy to promote the sales of environmentally friendly cars was introduced in April 2007. This was a result of an election campaign promise in the 2006 election. The subsidy was 10 000 SEK (1 000 euro) for a new car. It became very popular and greatly promoted the sales. It was in place until June 2009.
- No vehicle tax during the first years. A vehicle tax has to be paid for every car in Sweden, to help paying for governmental costs like road maintenance. When the environmental car subsidy was taken away it was supplanted by a reduction of this vehicle tax for environmentally friendly cars.

The support programmes for environmentally friendly cars have been successful in the sense that they have promoted the sales of these cars, and indirectly lead to increased sales of biofuels. But the measures have also been criticised for promoting car sales in general, instead of stimulating other measures to reduce the emissions from traffic, like public transport, cycling, and encouraging less car travel in general.

For biofuels, the different measures helped increase the market for E85 and for biogas. For biodiesel, these measures were of lesser importance, as there was no market for pure or high blend biodiesel.

Biofuels in heavy-duty vehicles

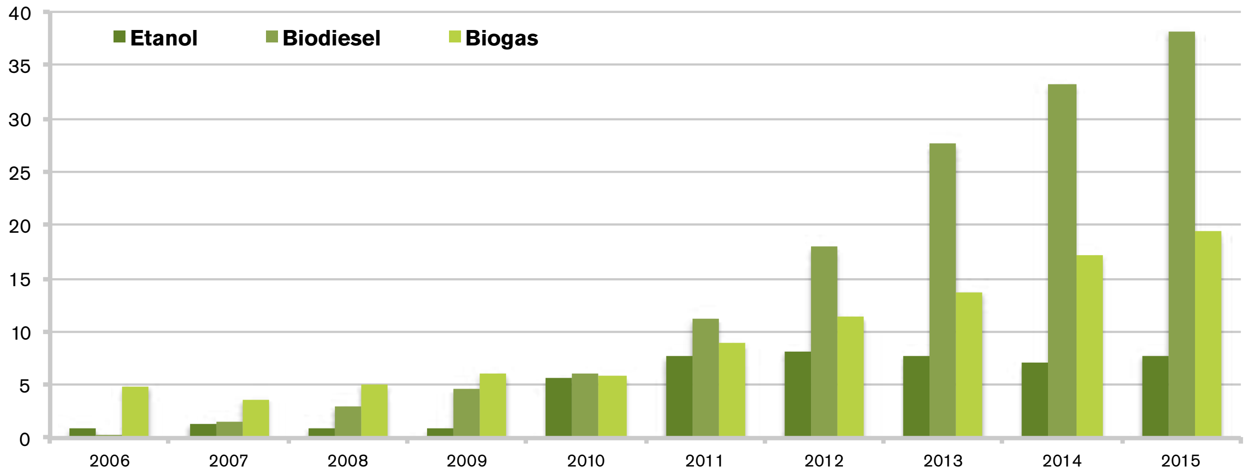
During recent years, biofuel use in heavy-duty vehicles has increased markedly.

The use of ethanol in buses started already in the late 1980s, as already mentioned. In 2015, almost two-thirds of all buses in public transport use biofuels: biodiesel, biogas and ethanol. The public transport systems are financed and organised by regional councils, and their procurement is a major mover of the market. Within a few years, all buses will run on renewable fuels, including also renewable electricity.

For trucks, biodiesel is the dominant biofuel, and a number of large carriers are switching fuels in their truck fleets. Biodiesel fuels can either be RME, rapeseed diesel (B100), or HVO diesel, that can be blended with regular diesel up to 100 percent.

Scania, the Swedish maker of heavy duty vehicles, is developing technology for biofuels in buses and lorries. The company made the first Swedish ethanol buses in 1987.

Photo: Scania



BUSES IN PUBLIC TRANSPORT USING BIOFUELS (%)

In 2015, almost two-thirds of all buses in local and regional public transport used biofuels. Number of buses using ethanol, biodiesel and biogas, as a percentage of all buses in public transport.

Source: Svensk Kollektivtrafik's database

Tax exemption for biofuels

Whereas the measures to promote environmentally friendly cars had a significant impact on developments, the major incentive to promote biofuels has been the general tax exemption for renewable fuels.

Taxation of petrol and diesel is heavy in Sweden, as well as in all other European countries. The tax consists of a general energy tax and a carbon dioxide tax.

When the first large ethanol plant was built in 2001 the Swedish parliament also decided on a general tax exemption on biofuels. The biofuels are neither charged energy tax, nor carbon dioxide tax. The support system is currently under review (2015) and the tax exemption may be replaced by a quota system based on the climate efficiency of the different fuels.

The tax exemption had to be permitted by the European Commission and show compliance with the EU state support regulations. It has been extended several times. The system gives a strong support to biofuels. The disadvantage is that the support scheme does not give the long-term guarantees needed by the market actors and investors.

Imported ethanol from Brazil

Sweden has traditionally been a "petrol country" more than a "diesel country", in contrast to most of Europe, but similar to the U.S. Therefore, it is natural that Sweden firstly focused on ethanol more than on biodiesel.

The Swedish production of ethanol has mainly supplied the low-blend market, and there are more projects in the pipeline for expanded domestic production of ethanol. The new projects will also be bio-refineries or combinates using biomass for energy input, and producing other energy products, like biogas, electricity and heat.

The Swedish raw material base for ethanol production of “the first generation” is limited, however. From the outset Sweden has also imported large quantities of ethanol, mainly from Brazil. The Brazilian ethanol has big advantages. It has a low production cost, and the production is highly efficient with very favourable greenhouse gas balance and energy balance. The production cost of Brazilian ethanol has been lower than the world market price of petrol for many years. With current, and, probably more so, future high oil prices, sugar cane ethanol will be ideally positioned to compete on the transport fuel market even without subsidies.

At the same time it is important for the European countries to build a domestic biofuel industry. The main reason is “security of supply”, and large untapped agricultural resources that can be used for biofuel production. From a climate policy standpoint there should be room for both domestically produced biofuels and imported tropical biofuels – the total demand for biofuels will be that large. The challenge here is to find a support system that enables a “balanced approach”.

Biofuels can be made from black liquor in pulp factories by means of gasification. The fuel is DME, dimethyl ether. A pilot plant was built in Piteå, and the technology is developed by Chemrec.

Photo: Chemrec

Biodiesel in Sweden

As mentioned previously, Sweden has traditionally been a petrol country. Diesel has mainly been used for heavy duty vehicles. It was therefore natural that ethanol became the first broadly used biofuel for transport.

However, a few enthusiasts started working on biodiesel relatively early, making biodiesel from rapeseed. The first facility producing RME (rape methyl ester) was built in 1983. A larger factory was built in Karlshamn ten years later by Lantmännen, the same farmers-owned co-operative company that built the ethanol plant in Norrköping. An even larger RME plant was built by Perstorp in Stenungsund, the petrochemical industry centre on the west coast. A number of smaller biodiesel plants were built by rapeseed producing farmers.

Low blend of RME in diesel was first introduced in 1996 at a 2 percent level, but it wasn't until 2005 that biodiesel blending became common. This level has increased up to 5 percent today.

In recent years there has been a strong shift from petrol to diesel as a fuel for cars, and sales of efficient diesel vehicles have increased. As a consequence, the volume of low blend biodiesel has increased. Also, high blend or pure biodiesel (B100) has become a more widespread fuel for heavy-duty vehicles.

HVO from tall oil

In 2011, Preem, Sweden's leading refinery and oil company, introduced a biodiesel based on tall oil. In Evolution diesel, the biodiesel content was raised to 20 percent, and in 2012 to 30 percent. The biodiesel was an HVO fuel, hydrogenated vegetable oil, a biodiesel quality that closely resembles regular diesel, and can be blended in higher levels than conventional biodiesel, RME, and still meet the specifications of diesel fuel. This is also called a "drop-in fuel". The raw material is supplied by Sunpine, a factory in Piteå in northern Sweden, that refines tall oil from pulp mills to be further refined by Preem. The capacity of the plant in Piteå is around 100 000 tonnes per year. HVO can also be made from a number of fatty products, like recycled vegetable oil and fats from slaughterhouses.

The production unit for tall oil diesel at the Preem refinery in Gothenburg.

Photo: Kjell Andersson

Second generation biofuels

The current production of biofuels from agricultural products like sugar cane, corn, wheat, rapeseed and palm oil, is usually characterised as "first generation biofuels". The processes are simple, familiar and centuries old, and the biomass raw materials used are rich in either sugar, starch or oil. To produce liquid fuels from cellulose is, in comparison, much more difficult and expensive. But using cellulose-rich biomass would greatly expand the raw material base for the biofuel industry, as the supply of low-cost cellulose is very large. Moreover, the risk for allegations of direct competition with food production will be reduced. Therefore we see a big push for "second generation biofuels", and relatively more research money devoted to developing such processes.

A number of different production paths are being explored, in Sweden as well as in other countries. These different paths will result in different end products. Here are some examples of the technologies that are being explored in Sweden today:

- Ethanol from cellulose by hydrolysis or enzyme processes. In these processes the cellulose is broken down to sugar and finally the sugar is fermented to produce ethanol. It is relatively difficult to break down the large cellulose molecules, and the total efficiency is not particularly high. Different cellulosic raw materials are more or less easy to handle.

The ethanol pilot in Örnsköldsvik has worked with woody materials, like saw-dust, but has also tested many other raw materials, like bagasse from Brazil. This project was started by Sekab and other companies in 2004, and was taken over by SP in 2013 as a biorefinery demo plant, where universities and companies can conduct research and technical development concerning cellulosic ethanol.

» Methanol from wood by gasification. The technology for production of methanol from wood is well-known, and there are advanced plans for industrial production (VärmlandsMetanol in Hagfors and by forest-based industries). The set-back so far for this path has been that the petrol distributors have been adverse to blending methanol in their fuels. Methanol is poisonous and more aggressive to the motors than ethanol. But at the same time there are obvious advantages; methanol production from cellulose is more efficient than ethanol production, and the process is well-established.

» DME from black liquor. DME is similar to methanol. It is a gas at atmospheric pressure, but turns to a liquid at higher pressure. DME can be produced by gasification of black liquor with a method developed by Chemrec, a Swedish company. The process is tested at pilot scale in Piteå, where a pilot plant today produces DME used to substitute propane. A large investment in a full-scale plant in Örnsköldsvik was not carried through, due to uncertainty about tax incentives and investment support. DME is considered a good alternative fuel for heavy-duty vehicles. The supply of black liquor is large in the pulp mills. To convert some of the boilers in pulp mills to gasifiers to produce DME would be a major technological shift for the Swedish forest-based industries.

Rapeseed is the predominant source of biodiesel in Sweden.

Photo: Sofie Samuelsson

» Bio-methane from forest residues through gasification. The GoBiGas-project in Gothenburg is a project to produce methane gas from forest residues and other wood fuels with thermal gasification. The gas will be fed into the natural gas grid and used mainly as fuel for vehicles. The GoBiGas 1 plant was opened in 2014 and was in full production in December of that year. The capacity of this demonstration plant is 20 MW and the fuel is wood pellets. It is currently the world's largest bio-gasification plant producing bio-methane. A second, larger plant with a capacity of 80–100 MW may be built in the coming years, depending on possible support schemes and market incentives for biofuels.

» Catalytic production of biofuels from lignin. Lignin is a major component in plants, but difficult to utilise except for combustion. In wood, lignin makes up a quarter of the biomass, and lignin is a major part of the

Tall oil from pulp factories can be transformed to biodiesel, an example of a second-generation biofuel. Tall oil diesel is already used in large quantities on the Swedish market, and produced by Sunpine and Preem. The picture shows raw tall oil and tall oil diesel.

Photo: Thomas Ögren

energy content of black liquor in pulp factories. Much research has been done on conversion of lignin to biofuels. One pathway is to use catalytic processes. The advantage is that this does not require high temperatures and pressures like gasification does. The Swedish company RenFuel is developing this technology with the aim to produce a drop-in petrol. The company recently received a grant to demonstrate the technology in a demo plant.

» Fuels from waste. Definitions of second-generation, or "advanced" biofuels differ. Some base the definitions on the technologies used to transform the cellulosic molecules, such as gasification, enzymatic hydrolysis or catalytic methods. Others base the definition entirely on the feedstock used, meaning that all biofuels from feedstock other than edible or agricultural can be defined as second-generation. With this latter definition all biofuels from waste products would also be second generation. In Sweden, there is today some production of ethanol from waste bread and candy, and other starch- and sugar-rich food waste, both at Agroetanol in Norrköping, and at a new small plant in Gothenburg, run by St1, an oil refining company and fuel distributor based in Finland and active on the Swedish market. Also, biogas for transport is almost entirely based on waste in Sweden, see page 49.

All these processes can be combined with other processes to obtain maximum energy output and maximum greenhouse gas reductions. By using excess heat, and producing electricity, by producing other chemicals, and by co-ordinating these productions with production of paper pulp or other fibres, pellets, etc, efficient biorefineries can be built, either as completely new industries, or by adding on to existing industries, like CHPs, pulp mills, chemical industries, or pellets factories.

Whether these second generation bio-industries will be successful depends on the economy – if they can compete on the market for fuels, and with first generation biofuels. Their advantage is that they can utilise inexpensive cellulosic raw materials that exist in abundance, among them many waste products and by-products. Their present disadvantage is the high capital cost for many of the processes, and the fact that investors are reluctant to take risks by engaging themselves in projects with new and unproven technologies.

The Swedish government and EU have shown great interest in these technologies and have given large economic support for research, pilot plants, and demonstration plants. For the final commercialisation there must also be equivalent support and further engagement and commitment from the private sector.

SOLID BIOFUELS FROM FORESTS

6.

◄ Slash piled up at the roadside, drying and waiting to be chipped and hauled to a heat plant. The slash is covered with brown paper to keep precipitation out.

Photo: Kjell Andersson

Solid biofuels dominate the Swedish use of bioenergy. To use biomass for energy purposes one usually has to prepare the biomass and turn it into a fuel. The preparation may be simple or more complicated. We talk about "unrefined solid biofuels" and "refined solid biofuels". The refined fuels include pellets, briquettes, and powder, all of which require drying, homogenisation and/or compacting.

Unrefined fuels

Even firewood must be prepared to be useful as a fuel. It has to be cut into logs and dried.

Bark, sawdust, shavings and other by-products from saw-mills and other wood industries may be used as fuels without preparation, other than transport and storage. These solid fuels can truly be seen as unrefined fuels, especially since they can be combusted with relatively high moisture content. In modern boilers with flue gas condensation the energy efficiency is still high.

Forest residues, recycled wood, and much of the waste wood at sawmills must be chipped or crushed, to be used as fuel. In Sweden, and Europe, chipping is the dominant method, whereas in North America crushing is much more common. Woodchips is a common fuel in most heat plants using biomass, as well as in many large boilers in forest-based industries. The chips are often mixed with bark, sawdust, peat, or other biomass materials before entering the boiler. Many boilers are built primarily to use chips.

From forest to heat plant

Forest residues, or slash, are the loose materials that remain in the forest after a thinning or a felling. In Swedish the term "grot" is commonly used for this material (grot = "grenar och toppar" in Swedish, means branches and tops).

After the felling, at the first stage the pulpwood and the logs are taken from the felling area to roadside, to be collected and brought to the industries, to pulp factories and sawmills. Debarking is done at these industries. At the second stage the slash is collected, and also taken to a roadside location close to the felling area. The slash is often first assembled in piles on the felling area to make collection easier.

The slash pile at roadside can be several meters high, and is covered with a layer of brown paper, to protect it from rain and snow, and to speed up the drying process.

The slash pile will usually be left to dry for several months – preferably over the summer. The moisture content goes down from over 50 percent in the fresh material to 30 percent or less, using the sun and the wind for drying, and increasing the energy value per tonne.

An alternative method is to bundle the slash and let the bundles dry in the forest, or take the bundles directly to the heat plant. Bundling technology has been developed in Sweden and Finland, and bundling is more common in Finland today than in Sweden.

The slash piles in the forest make up the major part of the stored fuel. Instead of assembling large amounts of fuel at the heat plants, the residues are left in their piles in the forest until the fuel is needed.

The slash will be chipped at roadside as the energy plants in the area demand fuel to feed their boilers. Mobile chipping units move from site to site. The chipped fuel is blown by the chipper into containers and transported by a truck to the energy plant. For larger plants, it is also common that the comminution is carried out at or close to the plant's site.

At the heat plant the truck's fuel load is weighed and the moisture content in the load is measured. The pay from the heat plant is based on energy content, not on total weight.

Finally, the chips are unloaded into a fuel storage bin at the plant, to be taken into the boiler by conveyor belts or screws.

It is possible to burn chips also without drying them. Modern boiler technology like flue gas condensation makes it possible to recover more energy also from fuels with high moisture content, thus using "green chips" instead of "brown chips".

A large chipper at work.

Photo: Alan Sherrard

Ash recycling

After the combustion of the fuel the ashes are collected (bottom ash and flue ash). If the boiler uses only wood fuels the ashes can be recycled and taken back to the forest for fertilisation. Ash recycling is practised in particular in areas in southern Sweden with acidified soils, as the wood ash has a high pH value. There is a strong impetus to increase the recycling of ashes back to the forest. The ash has to be stabilised before it can be recycled. It rests for at least three months and the pH value decreases to a level where it can be spread without harm to the vegetation in the forest. The ash is then pelletised and often spread together with fertiliser. The ashes do not necessarily go

Ash recycling is common in southern Sweden, where many forests have high acidity due to acid rain.

Photo: Svenska Energiaskor

back to the same areas where residues have been collected. Instead young stands with a need for fertilisation and higher pH are chosen.

Ash recycling means that valuable nutrients are brought back to the forests, and further, that these ashes do not need to be stored or taken to a land-fill. Swedish companies have developed machinery for ash recycling.

Regulations for slash harvest

Each forest owner has to report planned fellings and thinnings to the forest administration beforehand, and comply with a set of rules and regulations aimed at protecting the local environment.

In the report the forest owner has to specify if slash will be harvested.

The forest authority can stop a planned felling, if the legislation is not followed, or it can impose specific regulations.

The environmental conditions that must be met at a felling include:

» Protective zones along lake shores and waterways (rivers, creeks).

» Protection for wetlands (swamps, bogs).

» Protection for biodiversity, e.g. “key biotopes”, specified through inventories and mapped. Each forest owners is obliged to give such protection up to a certain share of the property area without economic compensation from the governmental.

» Leaving a certain amount of dead coarse wood in the forest. This can be dry trees, high stumps, etc.

» Leaving certain tree species, in particular broadleaf trees.

» Reforestation of the site. This can be done either by planting or by natural seeding from trees that are left. Only indigenous species like Scotch pine and Norway spruce are planted today. Special permits from the forest authorities are needed for planting non-indigenous species.

The requirement to replant and guarantee sustained future forest conditions has been part of the Swedish legislation since 1905.

For forest residues there are special restrictions against removing slash in certain areas, e. g. on dry soils and soils with low nutrient content.

Reforestation after final felling of a stand can either be done by planting or by natural seeding from trees that are left. In this case pines were left for seeding. (Although the small plant seen here is actually a spruce.) After a few years, when the new plants are established, the seeding trees will be cut down. A new young forest is ready to sequester carbon, and produce new biomass.

Photo: Kjell Andersson

A large crusher from Allan Bruks AB handling stumps in the forest.

Photo: Allan Bruks

Stumps contain large volumes of biomass. When harvesting stumps, it is essential to get rid of dirt and stones.

Photo: Sofie Samuelsson

Harvest of stumps

In recent years a new interest has arisen in using stumps and roots for energy, both in Sweden, and in neighbouring Finland. The total volume of stumps is quite large, compared to the volume of branches and tops (grot). However, only a limited share of the total stump volume will be considered for energy use. Reductions of the volume will be made for the following reasons:

- Broadleaf stumps will not be used – mainly for environmental reasons. Broadleaf dry wood needs to be saved in the forest.
- Pine stumps will in general not be used. These stumps decompose slower than the spruce stumps, and from a carbon balance standpoint it is good to leave them in the forest. Pine also grows on dry land where the root systems are important to bind the soil. Pine stumps are also harder to harvest than spruce stumps.
- This leaves primarily the spruce stumps, which make up less than 45 percent of all stumps.
- Stumps from thinnings will not be used – only stumps from final cuts.
- Stumps from wet areas will not be used, as these are difficult to harvest without damaging the soil and water balance.

Considering all these restrictions, only one sixth of the total yearly volume of new stumps in the Swedish forests will be considered for stump harvest. Still this would be a volume of 10 TWh biomass for energy – or close to 1 million tonnes of oil equivalents, enough to heat half a million homes in a sustainable way.

Stump harvest requires different technical solutions compared to slash harvest. The stumps have to be dug or pulled out of the ground, transported to roadside and piled up to be dried by sun and wind. Chipping is not possible, as the stumps may contain rocks and pebbles. Instead the stumps will be crushed. The comminution of the stumps will be made by roadside, just like chipping of slash. The alternative to transport whole stumps and crush them at the heat plant will be an option for larger sized plants. Contamination by stones and soil is an acknowledged problem, which can lead to high ash content in the fuel.

Stump harvest is so far only practiced to a limited degree in Sweden, but a rapid expansion can be foreseen if the market demand for solid biofuels increases.

Slash from small trees and thinnings

Beside stump harvest, harvest of small trees from thinnings is considered to have the largest potential to expand biomass recovery from forestry, once the use of slash from final felling has reached its limit. In Swedish forestry, the stands are thinned several times during a rotation period. In the first thinning some production of pulpwood for industrial use is taking place, but it generates large amounts of slash – small trees and bushes. Much of this material is birch, which has high energy value. Second and third thinnings produce pulpwood and some logs, but also some slash.

Replacing the traditional "first thinning" with energy thinning can be done in an economical way by using machines that cut, bundle and forward full trees in a combined process. Much work has been done by researchers and machine companies to develop this technology. The practical application has so far been quite slow. One reason can be that contractors are reluctant to provoke the pulp industry by entering into direct competition for pulp wood.

Slash from small trees and bushes from thinnings may be a future large source of forest biomass.

Photo: Kjell Andersson

Production of refined solid biofuels

The major categories of refined solid biofuels are pellets, briquettes, and powder. Of these, pellets are by far the largest. Wood pellets are today a major global commodity, traded in increasing volumes between countries and continents. Standardisation and certification has been developed to facilitate and increase this trade and give quality guarantees to the costumers.

Sweden is a leading user and producer of wood pellets in Europe.

A machine cutting small trees in a thinning operation.

Photo: Sofie Samuelsson

Background to the Swedish development

The technology to burn wood pellets in private homes for heating was developed in the United States. The forerunner was the company Whitfield. The first pellet stoves were imported to Sweden in 1988. Shortly thereafter Swedish companies started to develop their own stoves, boilers and burners for pellets. The most important products were pellet burners that could be directly installed in existing oil boilers. The earliest companies to use this technology were Ecotech, at that time located in Gothenburg, and Janfire in Åmål.

Production of pellets from Swedish sawdust started in the early 1980s. Sweden's many sawmills produce large volumes of sawdust. The sawdust was partly used by the panel industry to produce building and furniture material. Much of the sawdust was also burned in boilers and dryers in the sawmills

Pellets are produced from sawdust and shavings in 80 factories around Sweden. The picture shows the pellet storage silo at Derome.

Photo: Derome

and other forest-based industries, but the sawdust was generally regarded as a waste product to dispose of.

The first regular pellet factory was built in Mora in 1982. Unfortunately this project never worked well. It was a stand-alone unit with used equipment, and the staff did not have the right experience. There was also problems with the raw-material. Ultimately the factory was a setback to the pellet industry.

The big take-off rather took place when the Stockholm city energy utility decided to convert one of its main heat and power plants, Hässelby, from fossil fuels to biomass, and decided to try pellets. The demand for pellets suddenly increased by several hundred thousand tonnes, and lead to investments in a number of pellet factories along the northern Swedish coast, where many forest-based industries are located. Pellet factories were built in Härnösand, Skellefteå and Luleå, and pellets was transported by boat to Stockholm, beginning in 1993.

Another large conversion from coal to pellets took place in Helsingborg in the south. In this case, pellets were imported from Canada, and this was a starting point for Canadian export of pellets to Europe.

In parallel, pellet factories were also built in the south, where forests grow faster than in the north, and where a large number of sawmills are located. The leading pellet producer in the south was Svensk Brikettenergi (today part of Lantmännen), followed by Såbi (today part of Neova).

During these early years the emerging pellets industry met much resistance from the other users of sawdust, primarily the panel board producers. They lobbied hard and proposed a tax on sawdust used for energy. This special levy was much opposed by the pellet industry and Svebio. Until 1993 a special permit was required to use more than 10 000 cubic metres of saw dust or shavings for energy production, according to the Wood fibre law. After 1993 the use of these by-products was freed from governmental regulation.

The production of pellets has steadily increased. New producers have emerged, and today there are around 70 production units in all parts of the country. Wood pellets are produced by several of the large forest companies (Södra, Stora Enso, SCA/Norrenergi), by independent producers buying raw material (Agroenergi Neova Pellets, Rindi, Laxå Pellets), by sawmills with integrated production (Forssjö Pellets, Derome), by heat and power producing utilities (Skellefteå Kraft, Falu Energi & Miljö, Uddevalla Energi), and by many small-scale producers.

Future development of pellet production

A significant development in recent years is that the production of pellets increasingly is becoming a part of combinates that also produce heat, electri-city, and possibly liquid biofuels as well. Three examples are the CHP plants in Skellefteå, Falun and Uddevalla.

Another development is research and development of new technologies to increase the energy value per tonne of pellets. Torrefaction is a process where the pellets are "roasted" at a temperature of 250–300 °C. This product has been described as black pellets, or "green coal". The latter term can be misleading, since it is not charcoal, but a fuel that still contains about 90 percent of the energy content in the original pellets. And at the same time the volume decreases to 70 percent. The water content is only 1–2 percent. Torrefied pellets will have higher energy content per tonne and per cubic metre compared to conventional pellets. This will lower transport costs, and also simplify the use of pellets in co-firing with coal in power plants and in industrial applications. In Holmsund outside Umeå, an industrial demonstration unit for torrefied pellets was opened in 2015 by Bioendev. It will produce 16 000 tonnes annually.

A third development is use of new raw-materials beside sawdust and shavings. These by-products have a limited volume, and they are a direct result of the production volumes in forest-based industries. Already bark is used for pellets. It is also possible to mix peat into pellets. Instead of using wood only in the form of by-products, it is possible to use roundwood (stemwood). This is already done at a large scale in many new pellets factories in the Baltic countries, in Russia, and in North America.

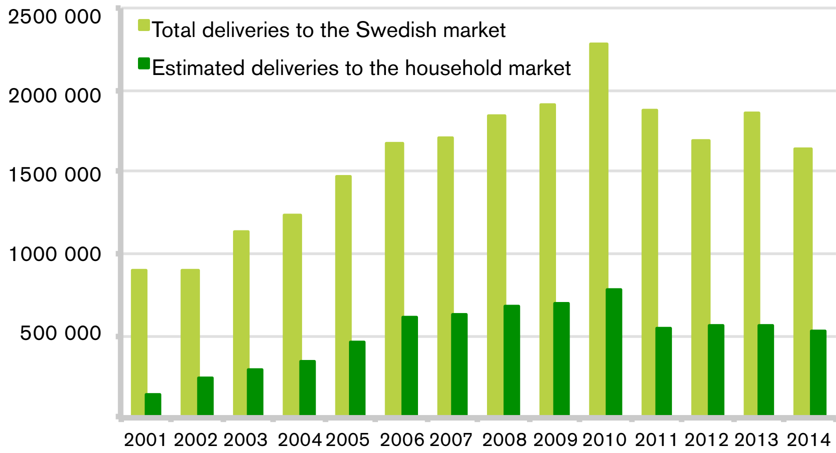
Another possibility is to make pellets from agricultural raw-materials. In Sweden this can be straw and other by-products, and energy crops like reed canary grass, willows, poplars and possibly hemp.

An overbearing future trend will certainly be increased trade with pellets. To facilitate this trade standards and certification schemes are developed. Sweden is today a leading producer of pellets in Europe and globally, and equally a big importer of pellets. Imports come from the Baltic countries, Russia, Finland and Norway.

PELLET DELIVERIES FROM SWEDISH PELLET PRODUCERS, 2001–2014 (TONNES) ➤

The deliveries from Swedish pellet factories depend on weather conditions and competition from imported pellets.

Source: PelletsFörbundet



The pellet market

The pellet market is usually divided into three sectors:

- » The residential small-scale market for heating of single houses. Deliveries to boilers up to 100 kW.
- » The middle-scale market where pellets are used for apartment buildings, small industries, and small heat plants. Deliveries to boilers 100 kW–5 MW.
- » The large-scale market for large heat plants and large industries. Deliveries to boilers over 5 MW capacity.

In all of these segments the major competition has been with heating oil, and expansion of pellets use has occurred because oil boilers have been converted to pellets. In the small-scale household market most oil boilers are already gone, and pellets heating now competes with heat-pumps and electric heating. The growth in this segment has slowed in recent years.

The middle-scale is the most promising market sector. The carbon tax has been increased on oil used in the industry, and the pellet price has been substantially lower than the price of heating oil in recent years. With an oil price of 100 dollars per barrel, this is equivalent to a pellet price of 250 euro per tonne. Pellets today cost 30 euro/MWh, equivalent to 144 euro per tonne. The competitiveness of pellets versus oil is therefore dependant both on incentives and oil prices.

For large-scale use there is competition mainly from cheaper solid biofuels, like chips and recycled wood.

Photo: Jonas Gustafsson

BIOGAS

7.

◄ One of Sweden's largest biogas plants is located in Linköping and owned by Swedish Biogas.

Photo: Svensk Biogas

When manure is used for biogas production, methane emissions to the atmosphere can be reduced.

Compared to the use and supply of solid biofuels the use and supply of biogas is still very small. Biogas, however, is a growing sector, and it has considerable political support. Biogas production helps to take care of waste products. Another reason is that biogas production and use can reduce emissions of methane, a highly potent greenhouse gas. This is often described as the double climate benefit of biogas and a motive for extra support to biogas.

Biogas is mainly produced from wet residues and waste products. The gas is used for heat and electricity, but also as a transport fuel.

Most landfills recover landfill gas, but this supply will dwindle in coming years, as it is not permitted to take municipal waste to landfills any more. This was forbidden for combustible waste in 2002, and for all organic waste in 2005. Such waste has to be used either for biological treatment (biogas fermentation or compost), or for incineration with power and heat production.

Most larger wastewater treatment plants produce biogas from their sludge. This is today the major source for biogas in Sweden.

In recent years a number of new biogas plants have been built, fermenting other waste materials, like food waste, sorted municipal waste, waste from food industries and restaurants, and manure. A couple of plants also use ley crops (grass and clover).

A large biogas plant in southern Sweden, Jordberga, uses different agricultural crops and residues, such as catch crops and silage from whole-crop wheat.

Direct investment grants have often been given to these plants under different governmental support schemes. Many have been built by municipal utilities.

Today, a major support scheme for biogas targets farmers. The purpose of this programme is to reduce the release of methane from manure. The production of manure-based biogas will give farmers financial support per produced kWh as reward for the reduction of methane emissions. The units must be small-scale – less than 500 kW for electricity or heating boilers, or less than 50 000 cubic metres of biogas per year when used as transport fuel.

Needless to say, biogas has the same favourable general tax rules as other biofuels.

The total production and use of biogas is around 1.5 TWh per year. The potential to produce biogas from wet residues and wastes is 3–4 TWh per year, according to a study by the Swedish Energy Agency.

Biogas is a mix of methane and carbon dioxide, and can be burnt and used for heat and electricity production. Biogas can be fed into the natural gas grid.

In order to do so it has to be up-graded to natural gas quality by cleaning it from carbon dioxide and adding a small proportion of propane. Up-graded biogas is almost entirely made up of methane. It can also be used as fuel for cars. A growing share of the Swedish biogas production is currently up-graded and used as transport fuel.

Bi-fuel cars that can run on biogas and/or a mix of biogas and natural gas, or on petrol or diesel, have been sold since around 2000, a total of 50 000 at the end of 2014. There were also 2 300 buses using biogas. A major hurdle for the expansion of biogas for transport is the high cost of gas pump installations. The investment cost is 20–30 times higher than installing a pump for E85. At the end of 2014, there were 155 public biogas filling stations, and 63 non-public biogas pumps, e.g. used for buses and taxis.

Biogas is more and more used as a transport fuel. It is also used for electricity production, in about 70 relatively small units.

Vafab in Västerås is a company producing biogas from a mixture of waste and ley crops. The waste products come from households, restaurants and food industries, the ley crops from farms around the city. The grass is stored as silage in large plastic tubes.

Potential and future development

How much more biogas can be produced and used in Sweden? The answer to this question vary greatly, also within the bioenergy community. Methane can be produced either by fermentation using microorganisms (traditional biogas), or by thermal gasification at high temperature (biomethane). For fermentation the raw material base is limited, and mainly consists of wet or moist waste and by-products from households, farms, food industries and restaurants, as well as manure and certain other waste products from farming and fishing. There are also waste products in forest-based industries that may be fermented. Another possibility is to produce biogas from by-products from ethanol production. Still, with all these sources the potential is limited to a few TWh. In some calculations, straw has been included as raw material for biogas production. Another potential source is energy crops like grass and clover (silage). In Germany and other countries, corn is grown for biogas production. In Sweden, corn can only be grown in a very limited area in the south. The use of straw and crops for fermentation increases the cost. Whereas waste products can be obtained for free, or a very low price, farmers have to be paid for energy crops. Straw can be used in heat plants or for pellet production. Estimates, which include straw and energy crops, raise the potential biogas production to an optimistic 10–14 TWh.

Using thermal gasification increases the raw-material base greatly, including biomass from forestry, and other cellulosic materials. On the other hand, the capital cost is high, and there is strong competition over the raw-material from heat and power plants, as well as from industries. Several projects for thermal gasification are under way, and the coming years will tell which technologies will prevail.

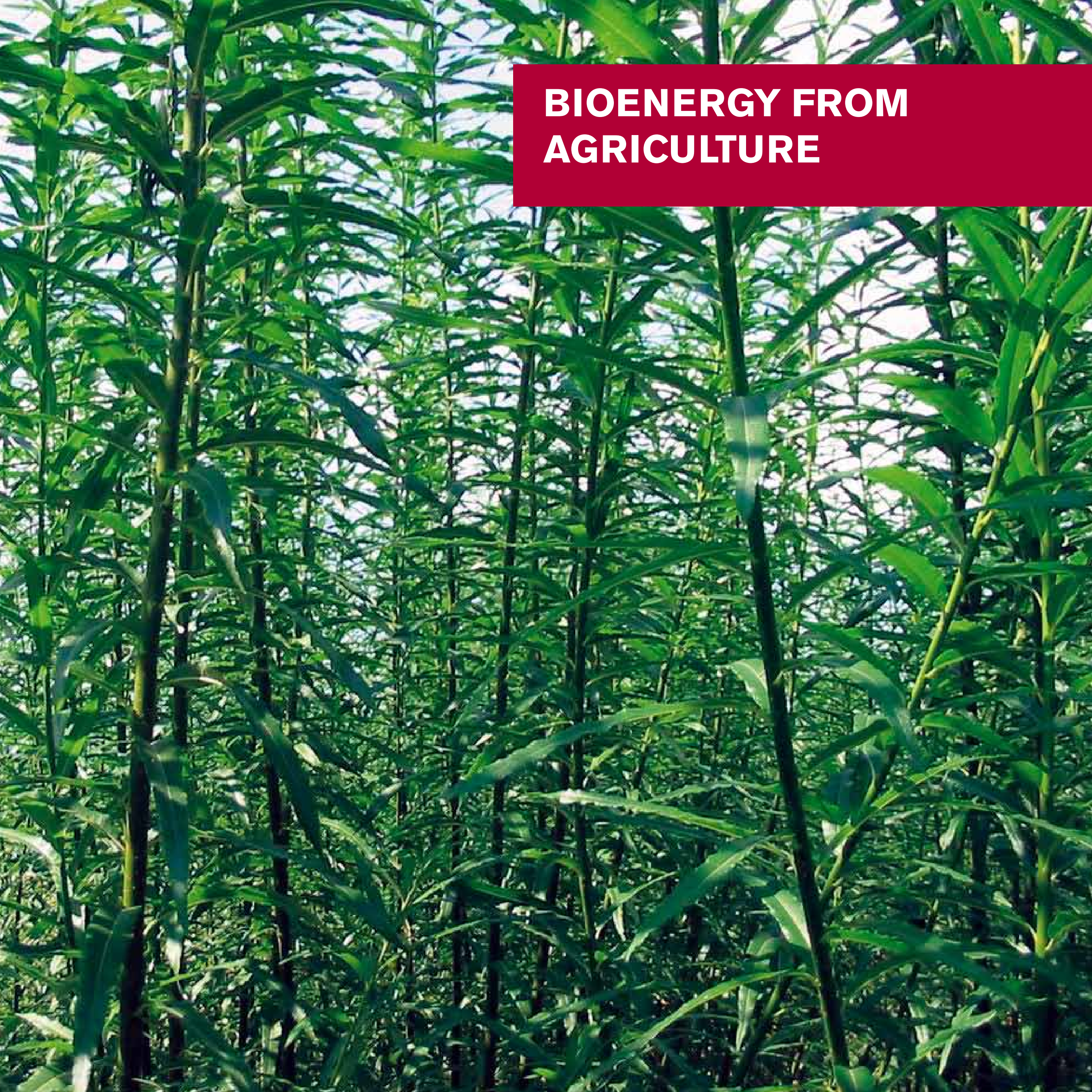
Optimistic estimates including the employment of large volumes of thermal gasification assume a rise to 70 TWh for biogas and bio-methane. This level has been questioned by many, among them the study done by the Energy Agency 2011, that concluded on a 3–4 TWh total biogas potential for Sweden.

◂ PUBLIC FILLING STATIONS FOR BIOGAS

The availability of biogas is a limiting factor for increased use of biogas for transport. Southern Sweden now has a relatively large number of filling stations for biogas, whereas in northern Sweden the number of stations is very low.

Illustration: The Swedish Gas Association, October 2015

BIOENERGY FROM AGRICULTURE



8.

As Sweden has such abundant biomass resources in forestry, less attention has been focused on bioenergy from agriculture than on forestry based biomass. Furthermore, it has not been easy for agricultural biomass to compete on a market overflowing with wood fuels. Agricultural bioenergy supply in Sweden today accounts for some 2–3 TWh, compared to more than 110 TWh based on forestry. These are the major bioenergy resources from farming used today:

- Wheat and other grains used for ethanol production.
- Rapeseed used for biodiesel production.
- Willows (Salix) produced as short rotation coppices (see next chapter), and used as chips for heat and power production.
- Manure used for biogas production (see previous chapter).
- Straw used in small local heat plants, mainly in southern Sweden. There are a few such small heat plants, often managed by local farmers and supplying heat to a small town or village. Straw is often also used in boilers on larger farms in agricultural areas. The boilers are often Danish, as Denmark has a much larger use of straw for energy than Sweden, also using straw in larger heat plants.

◂ Salix, or willows, can be grown as energy crops, producing large quantities of biomass. The coppices can grow several meters in a summer.

When grain prices have been low, grain has also been used in boilers for heat production, particularly oats. Horse manure can also be burnt in certain boilers. In northern Sweden reed canary grass offers an alternative to willows as a perennial crop. This grass is indigenous, and can produce large amounts of biomass per hectare. Another type of energy crop on farmland is fast-growing trees like poplars and hybrid aspen. These tree species can be harvested after 25–30 years.

Harvest of salix takes place after 3–4 years. With this machine the coppices are chipped directly in the field and blown into a container.

Photo: Bioenergiportalen

The Swedish salix programme

Short rotation coppice (SRC) production is a method to produce large volumes of cellulosic biomass on farmland. In Sweden, the preferred plant used for SRC production is willows – in Latin Salix. Swedish scientists at the University of Agricultural Sciences began developing salix energy plantations around the end of the 1970s, as an answer to the oil crisis. The leader in this field of work was professor Gustaf Sirén.

Salix can produce 10 dry tonnes, or more, of biomass per hectare and year under favourable conditions. A major advantage with SRC production is the very favourable energy balance. The field does not need to be tilled more than once in a 30 to 40 year rotation period. The only energy inputs are fuels for tractors and machinery at harvest once every 3–4 years, and energy for fertilisation, which is less than for yearly crops.

The willows are planted as coppice sticks, 30 cm long, around 10 000 per hectare. It is essential to fight competing weeds during the first years. After a couple of seasons the willows are cut back to produce more sprouts, and the first full energy crop can be harvested after 5–7 years. In the following years, harvesting is done every 3–4 years. Once a strong salix stand has been established, the same roots and stumps can produce fast growing coppices containing much energy year by year for at least 40 years. A big advantage compared to yearly crops is that the willow plants can utilise the whole growing season – from early spring well into the autumn.

With current methods, salix is harvested with harvesters that cut and chip the coppices and blow them into a container. With this method the chips are stored beside the field, but as the chips have high moisture content, they have to be taken to the heat plant within a couple of weeks. Harvest is preferably done when the ground is frozen in the winter months.

Researchers and companies are working on an alternative harvesting method, where the coppices are cut in full length and bundled. This method would make it possible to dry the willows before chipping, and enable the fuel companies or heat plants to store the fuel and increase the heat value. However, this harvesting method is technically more complicated.

Development so far

The basic research on salix was done in the 1970s and 1980s. Since then research has been focused on the development of breeds with higher yields and resistance to pests (fungi, insects). The yields from new breeds are typically 40 percent higher than for the breeds that were planted in around 1990. Also, breeds that can endure colder climate conditions have been developed.

When Sweden deregulated agriculture in 1990, large tracts of farmland became superfluous, farmland that had previously been used for excess grain production. Much of this land was of good quality, and much was subsequently set aside as fallow land. The government also supported conversion of farmland to energy crops. A farmer who planted salix would get a subsidy of 10 000 SEK per hectare to cover the planting cost. Within a couple of years, close to 15 000 hectares were planted with willows.

Since then, only a few hundred hectares per year have been planted. At the same time, some of the fields converted to salix in 1990–1991 have been changed back to grain production. The reason is that many of the plantations

Straw is used as fuel in a number of small heat plants in southern Sweden, and on many farms, in special boilers that can take large bales.

Photo: Bioenergiportalen

Straw bales and other farm residues are often burnt in cylindrical boilers.

Photo: Kjell Andersson

were not successful. Insufficient attention was given to the establishment of strong stands (weed reduction, etc), and sometimes poor soils, ill-suited to salix, were used.

Nevertheless, the overbearing experience of the Swedish salix programme is that well-managed salix plantations on good soils and with good breeds can produce high yields of biomass, and energy, at a low cost.

In the city of Enköping, west of Stockholm, a large salix plantation is part of an integrated project with the heat plant and the wastewater treatment plant. The salix plantation is irrigated with wastewater, and acts like a filter. The willows are then burnt in the heat plant, and the ashes are recycled.

Salix is today planted in many neighbouring countries with Swedish breeds, and the methods developed in Sweden are spread to new salix growers. Denmark, Germany, Poland, Scotland, Ireland and the Baltic states, are examples of countries adopting salix as energy crop.

Reed canary grass is an indigenous grass that is planted in northern Sweden and Finland for energy production.

Photo: Bioenergiportalen

Poplars or hybrid aspen

Growing poplars or hybrid aspen has become a popular alternative to salix as an energy crop on farmland. The production per hectare and per year is similar to salix, but the harvest only takes place every 15–25 years. After harvest, rejuvenation can take place with coppices. So far, around 3 000 hectares have been planted with these kinds of fast growing energy trees.

Reed canary grass

Reed canary grass is an indigenous grass that grows in wet areas. It is high yielding, but not suited for fodder or for grazing. The grass is perennial, and can be harvested for many years. It is usually left to dry through the winter to be harvested in the spring.

The grass can either be baled or pressed into briquettes or pellets. Reed canary grass is mainly seen as an alternative in northern Sweden, and in areas where salix does not grow well. The grass has been planted in large areas in Finland.

Another energy crop suited for the Swedish climate is hemp. It can also give high energy yields, but its main disadvantage is that it is not perennial, and therefore must be planted every year. The production cost is consequently higher than for reed canary grass. Also, the cost for seeds is relatively high.

PEAT

9.

One quarter of the land area in Sweden is covered with peat. Of this total peat area comprising 10 million hectares, about 6.4 million hectares have a peat layer of at least 30 centimetres (1 foot). The peat areas in Sweden are more than twice as large as the farmlands. Peat has traditionally been used as fuel, and for many other purposes, such as bedding in stables and as soil in greenhouses and gardens.

The use of peat as a fuel was very important during the world wars as substitute for imported coal; Sweden has very limited coal deposits. During the wars, when trade was disrupted, peat and wood stood for Sweden's security of fuel supply.

It was against this background that Sweden, during the oil crises in 1973 and 1979, naturally turned to peat to reduce its dependency on imported fossil fuels. Several heat plants were converted to peat, and governmental support was granted for investments in peat boilers.

Today the use of peat for energy is around 2–3 TWh per year. The total growth of peat layers in Swedish bogs has been estimated at 12 TWh per year, but this figure is uncertain.

Mixing 10–20 percent peat with other biofuels can reduce slagging in the boiler, as peat contains some sulphur. This, in turn, will reduce the maintenance cost.

Many Swedish peat bogs and swamps have been drained through the ages and turned into arable land (fields and pastures), or into forests. Many bogs have also been drained, in the process of harvesting peat. In many cases these bogs have been abandoned – but the drain ditches are still in place. These drained peat lands leak carbon, regardless of if they are used for energy purpose or not. To restore them to their "original state" is not always possible, and to let them return to water saturated swamps may lead to increased leakage of methane, a much more potent greenhouse gas than carbon dioxide. It would clearly make sense to use these already drained peat areas for energy purposes.

◀ After peat harvest is terminated on a bog, the area can be either planted with forest, or turned into a lake or a wetland.

Peat is harvested in the summer when the peat can be dried in the sun.

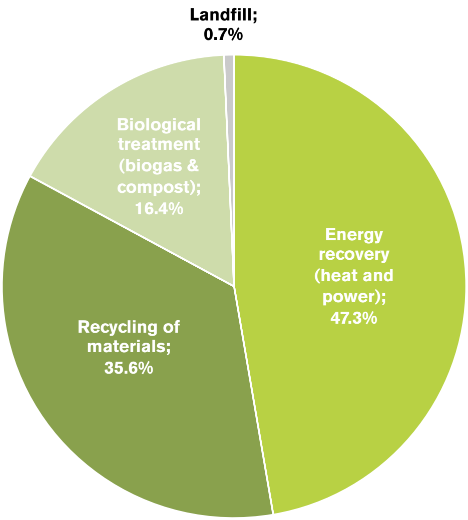
Photo: Marie Kofod-Hansen

WASTE TO ENERGY

10.

◀ The waste fuelled heat and power plant in Linköping is built with glass walls and located by the big highway. Burning waste is no secret in Linköping.

Photo: Åke E:son Lindman



USE OF HOUSEHOLD WASTE 2014

Only 0.7 percent of all household waste in Sweden was taken to landfill in 2014. Half of the waste was used to produce heat and power.

Source: Avfall Sverige

Since 2005 it is not permitted to take municipal waste to landfills. According to the Swedish waste laws the waste shall either be recycled or used for biogenic treatment (compost or biogas production), or be used for energy purposes (heat and electricity). In 2014, Swedish municipal waste was handled in the following ways: 47 percent was incinerated in heat and power plants, 36 percent was recycled as materials, 16 percent was used for biogenic treatment and less than 1 percent was taken to landfill. Swedish landfills have been transformed into recycling centres.

As "biogenic treatment" includes biogas production, more than half of the waste was used for energy purposes. Total energy production was 14.5 TWh, of which 2 TWh was electricity, and the rest mainly heat. A small part was biogas for transport. No incineration takes place without energy recovery.

There are today 34 heat plants using municipal waste. Almost all of them are combined heat and power plants, producing both heat and electricity. The power production is lower than in CHPs using wood. But municipal waste has to be burnt all year around, and these power plants therefore operate for many hours. They are typical base load plants. In the summer the energy is used for hot water production and for cooling, using absorption heat pumps. Many of the waste heat plants are located in large cities, to be able to take care of the produced energy all year around.

According to EU rules, half of the energy in municipal waste can be seen as biogenic in the energy statistics. Measurements of Swedish waste shows that this ratio is higher, probably around 58 percent. From the total volume, more than 80 percent of the waste is of biomass origin. The fossil content is primarily plastics, but also synthetic rubber, synthetic fibres, paints, chemicals, etc.

An environmental target has been set by the Swedish parliament to reduce the volumes of waste. But contrary to their aims, the waste volumes have continued to increase. Reduced volumes to landfills will gradually decrease the production of landfill gas gradually in coming years.

The use of 15 TWh of energy from waste means that 4 percent of the final energy use in Sweden comes from solid waste.

Several new investments have been made in waste CHPs in recent years, and the import of sorted municipal waste and waste wood has increased. The favourable incentives and carbon tax on heat, combined with the large capacity in the plants, enables this import.

POTENTIALS FOR GROWTH OF BIOENERGY

11.

◀ Slash from thinning offers a large potential for future growth of supply. More thinning of the forest will increase the production and quality of the remaining trees.

Photo: Kjell Andersson

Despite the already widespread use of bioenergy, great potential for growth still remains. Calculations made by Svebio show that the supply of Swedish biomass for energy could almost double. These are the major remaining potentials:

» Biomass from forests.

  Forest residues/slash. Only about one third of slash from final fellings is used today – only at 70 000 of the 200 000 hectares of yearly final cuts slash is recovered. The potential to increase the use of slash could generate at least 15 TWh.

  Stumps. The total amount of stumps "produced" per year after fellings is close to 60 TWh. After different reductions, broad-leaf and pine stumps, young stumps, stumps from thinnings, stumps on slopes and wet areas etc. Around 10 TWh of spruce stumps in favourable locations can be used, or possibly as much as 20 TWh.

  Small trees from thinnings. The methods need to be further developed to cut costs. There is a need to increase thinning to improve production in Swedish forests.

  Wood of low value, "long tops". The price paid to forest owners for pulpwood is sometimes low, especially for wood from remote areas. Also, the forester may want to sell a larger part of the tree as fuel wood.

  The total use of forest biomass can probably increase to 125–130 TWh, which is an increase of 50–55 TWh compared to the current supply.

» The supply of residues from forest-based industries and black liquor is dependent of the development of these industries, but here we count on unchanged or only slightly growing supply.

» Biomass from agriculture. Only 2–3 TWh of biomass for energy is produced in Swedish agriculture (ethanol wheat, salix, straw, manure for biogas, etc). A public study a few years ago found that this amount under certain conditions, this amount could be increased to 30–40 TWh. This would for example include a full use of set-aside and marginal lands, and would also include rather massive plantations of energy crops, like salix, poplars and increased production of biogas from manure and crops.

- Waste to energy. The amount of waste is expected to increase by a few TWh yearly. If more of the waste is sorted, more material can be used for biogas production.
- Peat. A use of 12 TWh of peat from previously ditched peatlands would correspond to the yearly growth of peat in the country.

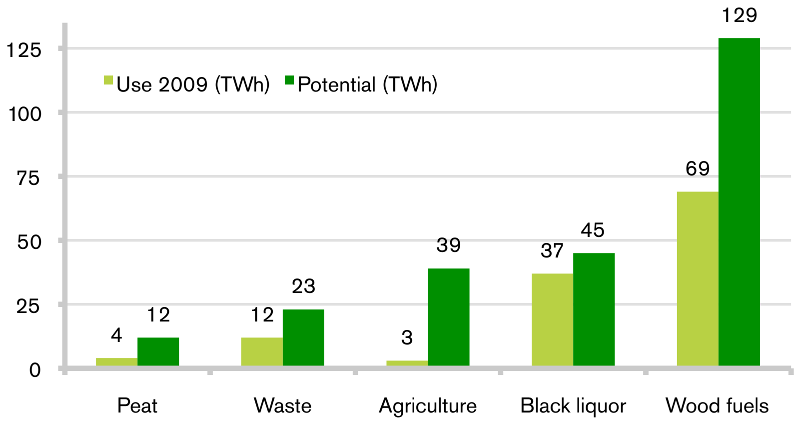
All of the above would mean a total potential of around 240 TWh in the medium term. Compared to the current supply of 140 TWh this is a significant remaining potential.

Long-term potentials

In the longer term the potential could still increase. The growth (increment) in Swedish forests is rising, and it follows that the total volumes of residues and by-products will increase. This is a result of ever better forest practices, better plant material, etc.

On top of this there is evidence that climate change will influence the Swedish forests favourably. The climate zones will move northward, the growth rates will increase, the forests will move higher up in the mountain regions, and the total forest area will increase. A governmental study in 2007 used climate models from the IPCC and came to the conclusion that Swedish forest growth would increase by 20–40 percent during this century.

Another potential is to establish fast growing forest plantations on forestland and on abandoned farmland (intensified forestry). Both coniferous trees like



POTENTIALS FOR BIOMASS IN THE MEDIUM TERM (TWh)

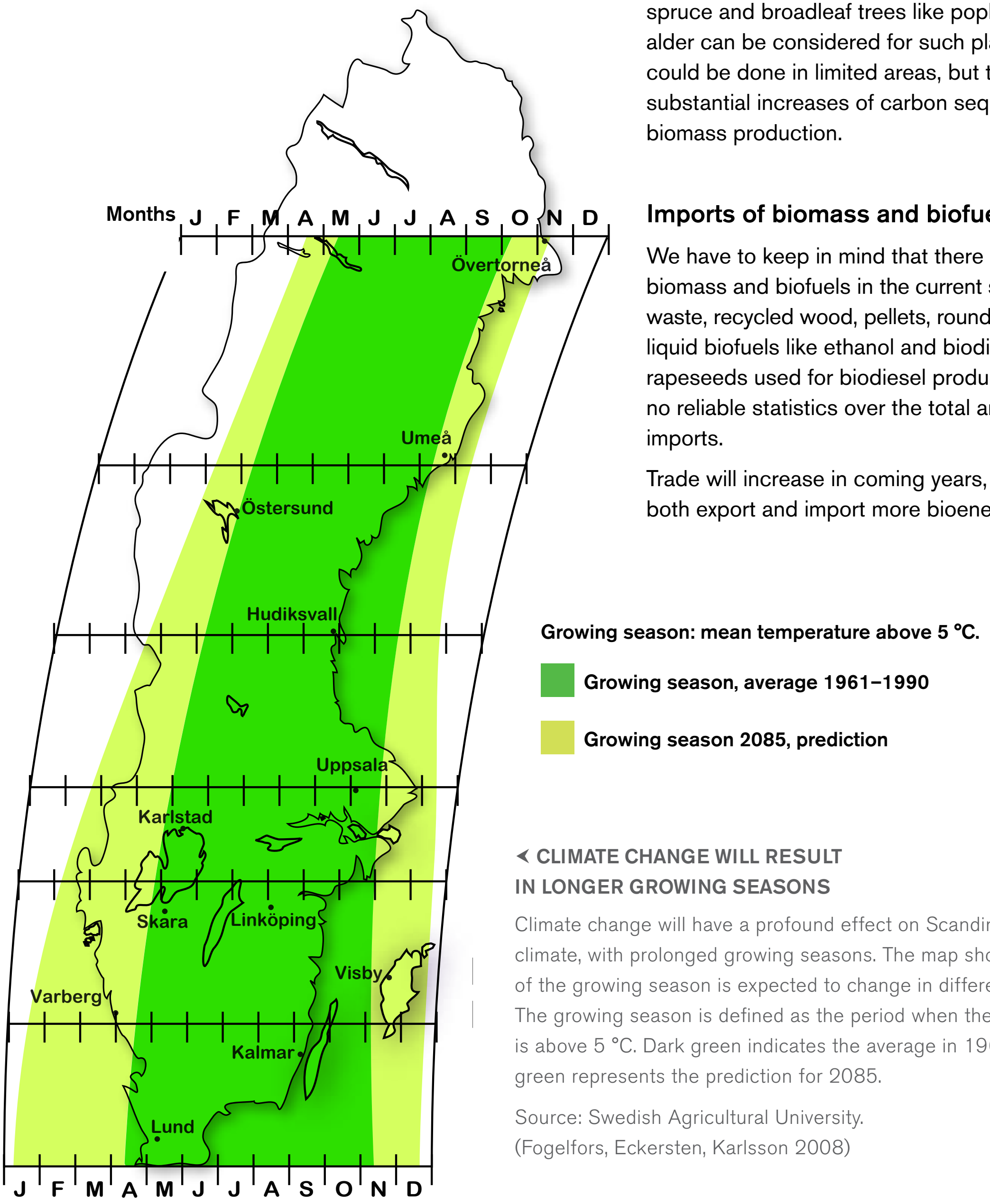
Svebio estimated potentials for supply of bioenergy available in a study in 2009, here compared to the utilisation at that time. The largest remaining potentials are in agriculture and forestry.

spruce and broadleaf trees like poplars, aspen and alder can be considered for such plantations. This could be done in limited areas, but this could still give substantial increases of carbon sequestration and biomass production.

Imports of biomass and biofuels

We have to keep in mind that there is some imported biomass and biofuels in the current supply: imported waste, recycled wood, pellets, roundwood, biooils and liquid biofuels like ethanol and biodiesel, and some rapeseeds used for biodiesel production. There are no reliable statistics over the total amount of these imports.

Trade will increase in coming years, and Sweden will both export and import more bioenergy.



◀ CLIMATE CHANGE WILL RESULT IN LONGER GROWING SEASONS

Climate change will have a profound effect on Scandinavia's regional climate, with prolonged growing seasons. The map shows how the length of the growing season is expected to change in different parts of Sweden. The growing season is defined as the period when the mean temperature is above 5 °C. Dark green indicates the average in 1961–1990, and light green represents the prediction for 2085.

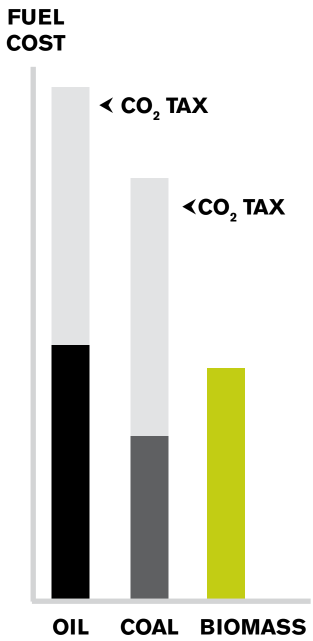
Source: Swedish Agricultural University. (Fogelfors, Eckersten, Karlsson 2008)

MARKET INCENTIVES AND ECONOMIC ASPECTS

12.

◂ Long range transport of solid biofuels from terminals by train or boat will level out prizes and widen the markets. This is terminal in southern Sweden.

Photo: Stockarydsterminalen



Paying for the CO_2 emissions with the carbon dioxide tax makes oil and coal more expensive and biomass more competitive on the market.

The Swedish carbon tax

This tax was the result of a public commission, which made proposals to "put a price on emissions", implementing the polluter pays principle (PPP).

The carbon tax was set to 0.25 SEK per kg of CO_2 (about 25 euro per tonne), and from the beginning was equal for all sectors of society.

The decision to introduce the carbon tax was taken by the Swedish parliament in 1990, and the tax came into force 1 January 1991. The tax was criticised by the Swedish industry with the argument that it put Swedish companies at a competitive disadvantage compared to industries in other countries. Soon after, the tax was lowered for industry, to 0.08 SEK per kg of CO_2. At the same time the tax was increased for households and for the service sector, to 0.32 SEK per kg of CO_2. Since then industries, as a whole, have had a reduced carbon tax. This difference will now be reduced for industries outside ETS (the European Emission Trading System), and these companies will pay 30 percent of the regular carbon tax from 2011, 60 percent from 2015, 80 percent from 2016, and full carbon tax from 2018.

The carbon tax has been increased several times since 1991. This was prevalent during the years of "green tax switch" (2001–2006). The idea of a green tax switch is that environmental taxes are raised, whilst at the same time as other taxes, such as taxes on income or on labour, are lowered. The principle is that the total taxation is unchanged, but the weight is put on taxation of emissions, whereas taxation of labour is lowered. This tax switch will stimulate growth for clean technologies and energy efficiency.

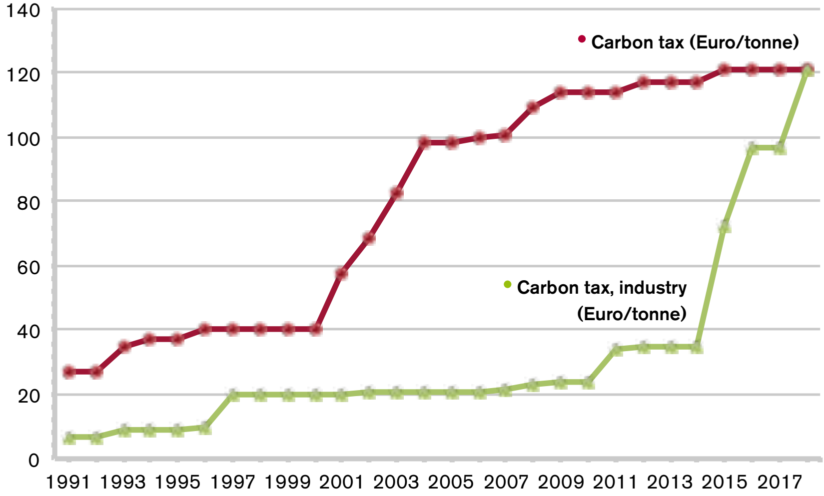
Today the carbon tax is 1.12 SEK per kg of CO_2. For the buyers of heating oil it means that the price is almost doubled compared to the market price.

When the EU Commission a few years ago proposed a common European carbon tax it was at a level comparable to the carbon tax introduced in Sweden in 1991, but only one fifth of the current carbon tax in Sweden. Since then, work on a new energy taxation directive has been put on hold.

The carbon tax has been the major incentive to reduce the use of fossil fuels, and the major driving force behind the rapid growth of bioenergy in Sweden. The transition has been strongest in district heating.

Bioenergy and employment

Virtually no research has been done on identifying the effects of the rapid expansion of bioenergy in Sweden on employment and economic development



◂ THE SWEDISH CARBON TAX 1991–2018

The carbon dioxide tax was introduced in 1991, and has been increased in several steps since then.

Red: the general carbon dioxide tax level, paid by the residential and service sector. Green: The tax paid by industries outside ETS that are not required to have emission allowances.

Source: Swedish Finance Ministry / Svebio

in general. One study in 1998 showed that each extra TWh of bioenergy use would result in 300 extra jobs in the whole supply chain. The study included all activities up to the delivery of heat or fuel to final users. The study did not include employment in construction, e.g. of heat plants. During an expansion phase with many large investment projects, there is of course considerable added employment in construction.

If this number (300 jobs per TWh) is applied to the whole bioenergy use in Sweden, it would mean that bioenergy results in over 40 000 jobs (140 TWh times 300). The large use of black liquor and other by-products in forest-based industries does not give these kinds of employment effects, however. A more reasonable number would be 25 000–30 000 jobs, based on the simple rule of thumb.

Boosting employment is not a primary motivation in itself. If the supply chain is efficient it should employ as few people as possible, to guarantee a competitive price compared to other energy sources, and profitability for the companies. On the other hand, with today's high unemployment numbers, every single job created is welcome in Swedish communities.

One big advantage with bioenergy is that the employment is spread over the whole country. This is of great significance to the smaller communities, and to rural development. The biomass resources are present in every municipality with

Many jobs are created in logistics and transport companies. This is a terminal where trains are loaded with biomass.

Photo: Stockarydsterminalen

fields and forests. Collecting biomass, and growing and harvesting bioenergy crops, offers jobs opportunities throughout the country, in forestry and in agriculture. Biomass is a decentralised energy source.

Manufacturing of equipment for the whole bioenergy supply chain offers many industrial jobs.

Photo: KMW

Employment in heat plants and heat and power plants is on the other hand concentrated to where people live and demand heat, primarily in the cities. Employment in pellets production is located close to the raw material, the sawdust being produced in sawmills.

A substantial part of bioenergy employment is the jobs in logistics and transport companies (lorries, terminals, ports, rail networks). The chips and pellets have to be transported to industries, heat plants and private customers.

Bioenergy and economic development

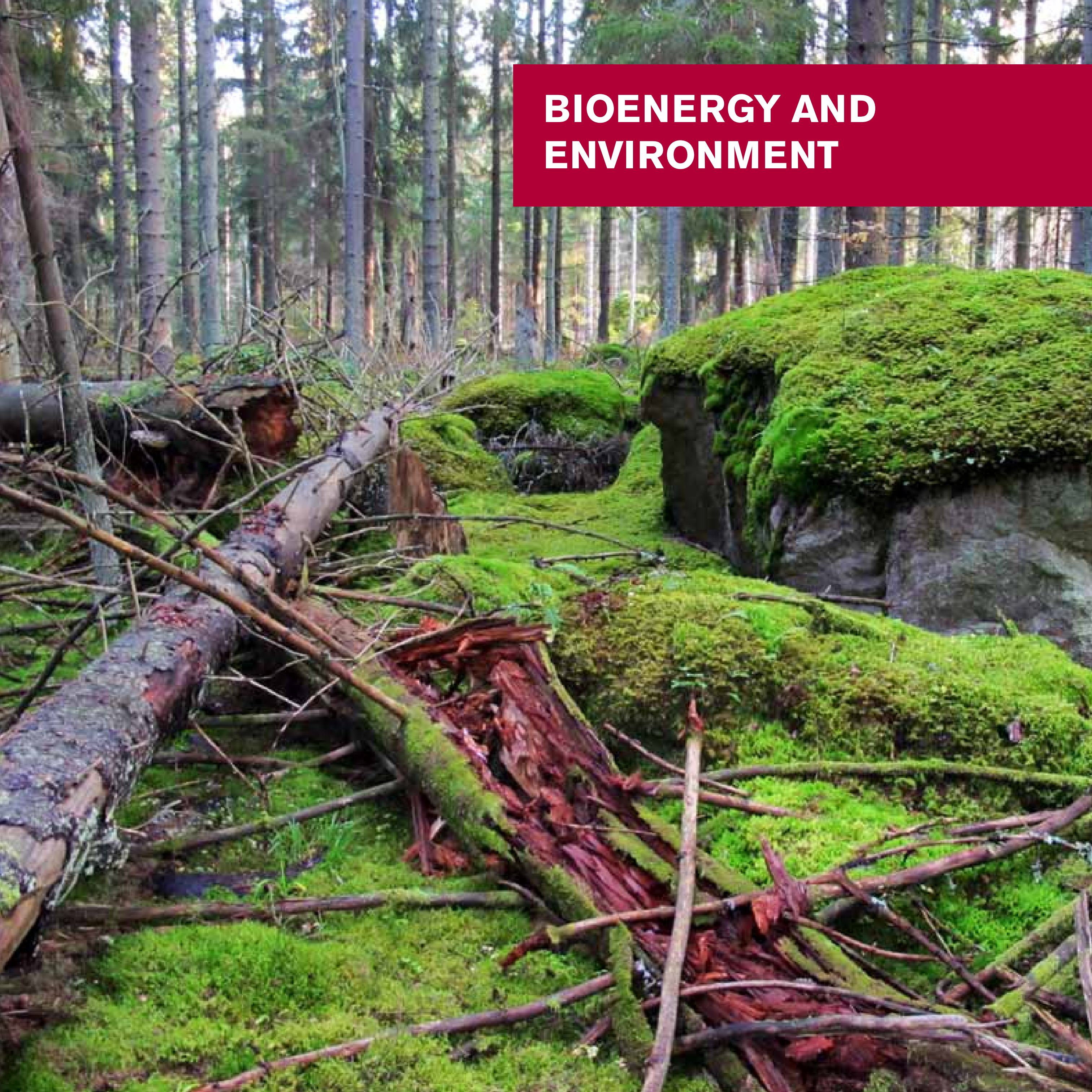
Using 140 TWh of domestic fuels instead of imported fossil fuels means that Sweden can avoid the import cost of these substituted fuels. Since the 1970s the bioenergy use has grown by 100 TWh. Most of the substituted fossil fuel was heating oil. A smaller fraction was coal. With a world market oil price of 100 dollars/barrel the total import cost of 100 TWh oil would be 40 billion SEK, or 4.5 billion euro. At half that oil price, the cost is that much lower. This is the annual avoided "oil bill" for Sweden, and a value of the reduced energy import resulting from our high use of domestic bioenergy. This is a serious advantage to the annual national economy.

Instead of paying this money to global oil companies and oil producing countries, the money remains in the Swedish economy, creating and maintaining jobs and employment around the country, and delivers taxes to the government and municipalities.

Building a domestic market for bioenergy has created a large number of companies in the bioenergy business sector. Their knowledge and technologies have a growing value on the world market, and many of the companies are engaging in exports and earning revenues for the Swedish economy. These companies embody a significant portion of the Swedish cleantech export capacity.

One can argue that the low dependency on oil imports in Sweden is one factor that has helped the Swedish economy to be stable in the recent recession. Since the 1970s Swedish oil imports have been reduced from 30 million tonnes per year to 11 million tonnes today. The rising oil prices created an extra burden on countries with high oil dependency, but to Sweden the rise in oil prices in recent years has been less harmful due to the lower oil dependency.

BIOENERGY AND ENVIRONMENT



13.

Bioenergy is reducing greenhouse gas emissions

Bioenergy has been a major factor in cutting greenhouse gas emissions in Sweden. In the initial phase during the 1980s the swift expansion of nuclear power lead to increased use of electric heating and the substitution of heating oil. Electricity was also used directly in district heating, used in electric boilers and in large-scale heat pumps.

In the second phase, roughly from 1990 onwards, bioenergy expanded quickly, and during the Kyoto period from 1990 until today, increased use of bioenergy is the major factor behind Sweden's reduced emissions of greenhouse gases, as reported to the UN climate conference.

◀ Coarse dead wood is essential for many organisms in the forests.

Photo: Kjell Andersson

Questions concerning sustainability

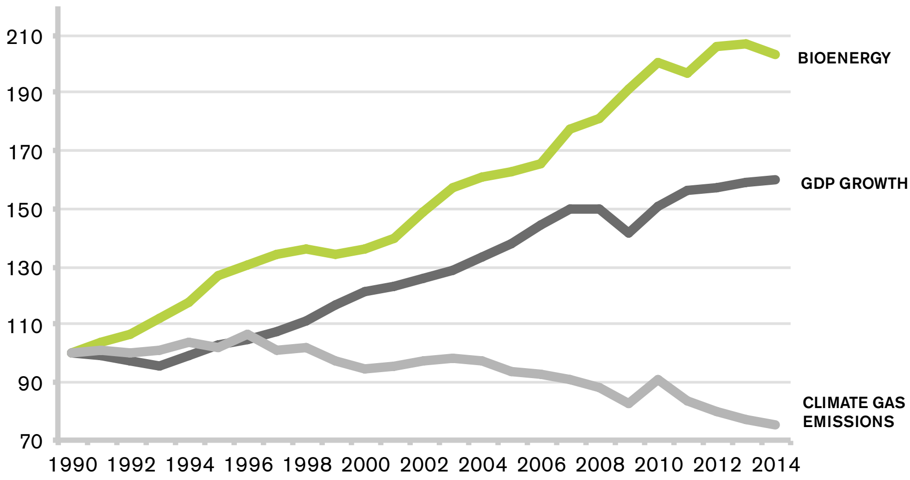
In recent years the sustainability of bioenergy has been questioned. Not so much on a national Swedish level, but more on the European and global stag. The early debate was heated and centred around biofuels for transport and bioenergy crops from agriculture. The ensuing debate has focused on a number of issues, like influence on food prices and food security, adverse affects on biodiversity, carbon balance, land use change, and indirect effects.

Here are some of the sustainability issues that have been raised concerning Swedish bioenergy production and utilisation.

DECOUPLING 1990–2014 ➤

GDP increased by 60 percent in real terms. Greenhouse gas emissions decreased by 25 percent 1990–2014, and the use of bioenergy doubled.

The diagram shows changes from 1990 (1990 = 100 percent).



The spruce in the background of this picture taken at the author's (in dark suit) confirmation in 1964 had been planted a few years earlier. Today the spruce is a big tree, 24 metres high, and 65 centimetres in diameter. The total biomass of the tree, including all the branches, can be calculated to 4.54 cubic metres, or 9.12 MWh.

"I plan to cut it down and use it for firewood, because it shadows the garden and blocks the view for drivers on the nearby road.

My question is: Am I causing a carbon dept that I have to pay back in the future, or am I just taking out a carbon asset, that my family has deposited in the carbon bank?

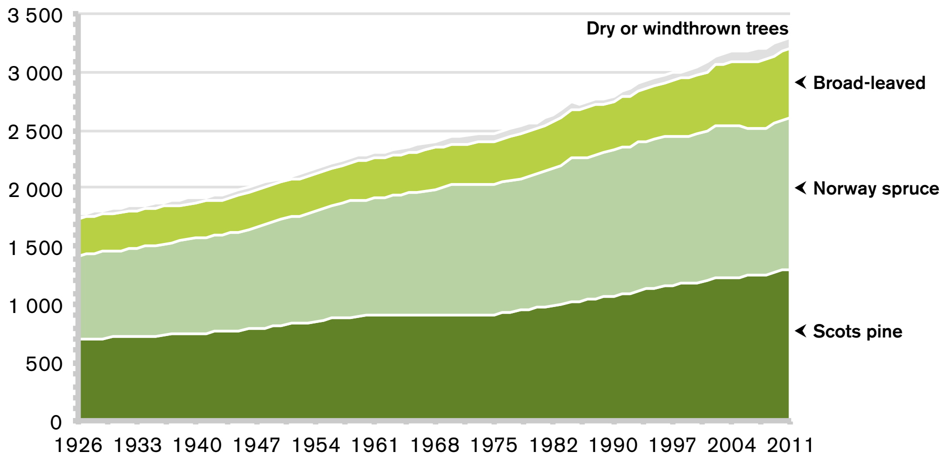
This is not the only tree in the area. Some are small and some are big, and they all grow and sequester carbon."

Photo: Suzanne Houske Andersson

TREND FOR TOTAL STANDING VOLUME IN FORESTS, 1926–2011 ➤

The total standing volume, and thus the amount of stored carbon, has doubled in Sweden's forests in the previous hundred years, thanks to reforestation and good forest management.

Source: Derived from official statistics from Swedish University of Agricultural Sciences, Swedish National Forest Inventory



Million cubic metre standing volume, stem volume over bark from stump to tip.

A postcard from 1902 shows barren surroundings around this church in western Sweden. Today there are trees everywhere. This is a common development in most parts of Sweden during the last 100 years. Less grazing (fewer milk cows and sheep), less use of firewood, better management of forests, etc, are the causes of this development.

Carbon balance

The production of biofuels always has a carbon budget, with plus and minus, whether the fuels are solid, liquid or gaseous. There is always an input of fuel and machinery, sometimes fertilisers. The transports of raw materials and end products require energy, often diesel. Refining also requires input of energy for processes.

When the plants or trees are harvested and the biofuels are combusted, the carbon in the biomass is released, and there is a time lapse before the equivalent amount of carbon is again taken up by new plants in the same location. Carbon can also be lost from the soil. Critics of bioenergy argue that these losses of carbon can be quite large, and that it takes a long time to pay back the "carbon debt" that is created when the trees are cut down.

Yet, concurrently, we know that the total quantity of carbon stored in our forests is growing year by year. Temporary carbon losses at individual stands of forest are compensated by increased growth and storage of carbon in other stands and forests. On a landscape or national level the carbon balance is positive, despite the fact that we harvest wood, used both for lumber, pulp and paper, and for bioenergy.

The standing volume of wood biomass in the Swedish forests has more than doubled during the last one hundred years. Every year Sweden has a positive figure for LULUCF (Land Use, Land Use Change and Forestry) reported to the UNCCP. This positive figure for forest growth and soil carbon is usually tantamount to half of the negative green house gas emissions from all sectors of society.

For different supply chains the carbon balances can be quite different.

If an energy crop is produced on land that previously was forest and if the farm practice involves heavy fertilisation, irrigation and use of much heavy machinery, and if the processing of the biofuel is done with fossil fuels like coal or natural gas, then certainly the carbon balance will be negative. No such production chains exist in the Swedish bioenergy industry.

If, by contrast, the same energy crop is produced on previously set-aside or fallow land, and the processing energy is taken from a biomass boiler, and the by-products are used as feedstuff substituting feeds with a large carbon footprint, or to produce biogas, then the carbon balance will be very good, and the reduction of greenhouse gas emissions will be substantial. Such supply chains exist in Swedish ethanol production.

The carbon balances for woodchips and wood pellets are in general extremely good.

On a global level the forest resources are increasing in most countries except the poor countries. Deforestation is tied to poverty and bad governance. Poor people have to cut down trees for firewood and practice slash-and-burning to farm. With economic development the protection of forests and replanting is improved. The Finnish professor Pekka Kauppi has shown that forest areas and growth increases in all countries with a GDP per capita over a certain level.

Young trees have the highest growth rate and therefore also the largest uptake of carbon.

Photo: Kjell Andersson

Energy balance

A common misconception is that the production of biofuels requires a very large input of energy, and that the energy output can be even less than the energy input. This is certainly not true. Plants and trees capture large amounts of solar energy and store the energy as biomass. To harvest, transport and refine this biomass to biofuels of different kinds in most supply chains only requires the input of a few percent of the equivalent energy content of the final biofuel.

This is certainly true for the common unrefined woodfuels, like forest residues, chips and bark. Energy for transporting the biomass and the final energy pro-ducts usually account for one or two percent. Drying fuels will consume extra energy. Therefore pellets have a less favourable energy balance than woodchips. The input of energy may be 10–15 percent of the final energy content, but most of that energy input is embedded in the form of an increased overall energy content. The energy for drying is as a rule bioenergy, like waste material produced in the pellet factory itself.

To guarantee biodiversity, “hot spots” in the forests have to be spared from forest operations.

Photo: Nina Soliva

Biodiversity

Most of the biodiversity issues surrounding bioenergy are the same as the biodiversity issues for forestry in general. And these issues are regulated in the environmental legislation and in the forestry legislation. There are no-go-areas like national parks and reserves, but also in regular forestry on productive forest land a number of conservational measures have to be considered. At final fellings a certain amount of coarse dead wood has to be left. Protective zones must be left around creeks and along lakes. Wetland must be left aside. Furthermore, the authorities have recognised biodiversity “hot spots” that must be preserved. It can be stands of very old trees, areas where rare plants grow, etc. According to Swedish law a private owner must act in accordance with such considerations up to a certain economic limit.

Specific biodiversity issues have been raised concerning stumps and slash harvest. Some conservationists and researchers fear that the amount of dead wood will decrease too much in harvested forest. The solution must be to find a balance between the ecological considerations and the need for renewable fuels and material. One must also bear in mind that the alternative is to use a fossil fuel.

Research concerning environmental effects of biomass harvest in forests has been done parallel to the growth of bioenergy use at the University of Agricultural Sciences, and at several other Swedish universities.

Nutrients and soil

Removing wood and slash from the forest means that nutrients are lost. Seen over a 70 or 100 year rotation period this is usually a marginal effect, but on certain poor and dry soils the effect can be more evident. One way to minimise the loss is to let the green matter, needles and leaves, stay in the forest. Another way is to recycle the ashes.

Only mineral nutrients, however, remain in the ashes. Nitrogen is lost in the flue gases. In south-western Sweden with excess nitrogen from precipitation, this is not problematic, but in other parts of the country the loss of nitrogen must be compensated for, e.g. by fertilising, in order to maintain productivity. To enable ash recycling the boilers need to use only clean wood fuels. To mix the fuel with fossil fuels or waste leads to contamination of the ashes.

Use of forest residues can also lead to decreased buffering capacity in the soil, with lower pH value. As the wood ash has high pH value this is also a strong argument for ash recycling.

Land use and bioenergy versus food

Sweden as well as all of the European Union and all of Europe has a surplus of arable land. Out of a total surface of arable land in Sweden of 3 million hectares, 0.8 million hectares are unused or used in a non-productive way. Growing wheat for ethanol and rapeseed for biodiesel does not compete with food production as long as these marginal land areas are used. In the EU as a whole at least 10 million hectares are set aside or not used for production. The EU has set aside another 5 percent of farmland as "ecological focus areas", which means another several million hectares. In eastern Europe outside the EU (Russia, Ukraine, Belorussia, Moldova, Croatia, etc), even more land is available for increased production of bioenergy crops without competing with food production. A recent satellite based study showed that there is more than 50 million hectares of abandoned farmland in eastern Europe, including Russia.

Addax has built an ethanol plant in Sierra Leone using sugarcane as feedstock. The Addax project shows that it is possible to produce energy crops and at the same time increase food production in the area. Photos: Kjell Andersson

Air quality

Heat plants using biomass have to adhere to stringent regulations for emissions. Flue gas condensation, mechanical filters and electrofilters are used. Nitrous oxide emissions is a particular problem for biomass plants. These emissions have been reduced considerably, and the reduction has been catalysed by an emission fee, punishing the plants with high emissions and rewarding plants with low emissions.

Waste plants have decreased the emissions of dioxins to extremely low levels. Emissions have been reduced by 99 percent from previous levels according to the Swedish Environmental Protection Agency.

Small scale boilers and ovens using firewood can sometimes have considerable emissions of carbon monoxide, particles, PAH and other pollutants.

BIOENERGY IS SOLAR ENERGY

The plants use photosynthesis to produce energy-rich carbohydrates. These carbohydrates are stored in the plants as biomass, and can be used for food for humans or feed for animals, or used as fibers or for bioenergy. The driving force for photosynthesis is the sun, and biomass is therefore stored solar energy.

Through this process the plants also sequester carbon dioxide from the air. The carbon taken out of the atmosphere by the plants is returned to the atmosphere when the plants decay, are consumed by humans, animal or microorganisms, or used burned for energy use.

Bioenergy is a renewable energy source the same way solar energy and wind-power are. A big advantage of bioenergy is that the solar energy is stored in energy-rich biomass and fuels.

This is especially true when old equipment is used, and when the firewood is not dry enough. Modern wood stoves and wood boilers have very low emissions, especially when they are combined with hot water accumulators, and are as good as pellet boilers. With pellets, the environmental problems with small-scale biomass heating is negligible. There are even pellet stoves on the Swedish market that do not require a chimney; the flue gas is so clean that it can be taken out through the wall behind the stove with a fan.

In theory, plants can capture up to 6 percent of the solar radiation. But in reality, most crops produce much less.

Certification and standardisation

Certification and standardisation are methods used to guarantee the quality and sustainability of different kinds of biofuels: solid, gaseous and liquid. The standards and certificates give the costumers information about the properties of the fuels and how they have been produced. For a young and fast developing business sector like modern bioenergy, it takes time to produce these standards and certification systems. Much work has been done in the European standardisation organisation CEN, e.g. to develop product standards for solid biofuels, like pellets. The business sector itself has developed its own standards, like the European pellets standard EnPlus.

During the last years a global standard has been developed for sustainability criteria for bioenergy (ISO 13065:2015).

Within EU, different directives with criteria and regulations act as a framework. The Renewable Energy Directive (RED), adopted in 2009, includes sustainability criteria for biofuels and these criteria have also been implemented in Swedish legislation. This means that all biofuels and bioliquids on the Swedish market today comply with common European sustainability criteria.

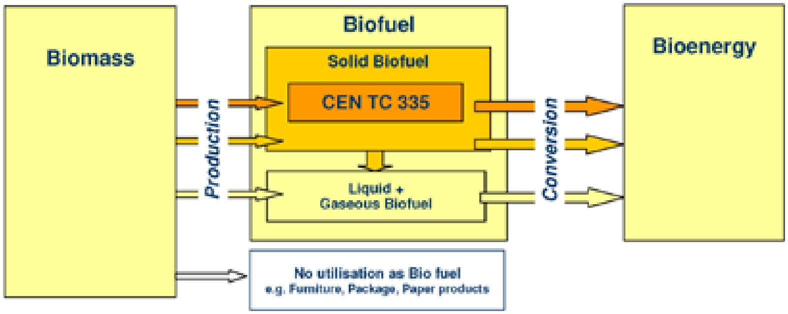
Definitions of bioenergy

What is bioenergy? It is energy from organic matter. Simple, or? There are several definitions, and the terminology used is not always logical.

CEN, the European standardisation organisation, has made this definition, which seems smart:

"Bioenergy is energy from biomass"

"Biomass is defined from a scientific and technical point of view as material of biological origin excluding material embedded in geological formations and/or transformed to fossil."



Definitions according to CEN TC335.

Comment: Biomass is what is produced in nature – all the organic matter present in a certain ecosystem – the plants, trees, animals, fungi, etc. The biomass is primarily produced by plants by means of photosynthesis, using solar energy to build carbon-rich components like cellulose, sugar and starch. The biomass is food for animals and microorganisms.

But how old can biomass be? All living matter is of course biomass. In northern Sweden, a few years ago they found a tree that was 4 000 years old.

Defining peat is a difficult matter. According to this definition it could be biomass, as it is not embedded in a geological formation. On the other hand, the peat used for energy is several hundred or thousand years old. And the peat is dead organic matter. Often, peat is branded as a "fossil". But with the same logic all dead organic matter in soils would be considered to be "fossil". The conclusion must be that peat is neither biomass nor fossil fuel but a category of its own, which has been recognised as such by the IPCC. The Swedish peat study in 2001 stipulated that peat is a "slowly renewable biomass fuel".

Dead wood is of course biomass. And so are dead plants, like straw.

This definition of bioenergy is used by the European Union in a number of directives:

"Biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste."

To use "biodegradable" as a prerequisite does not make sense. It is not the biodegradability that makes biomass into biomass, but its origin, the process

Trees can be seen as living solar collectors, using sunshine to produce biomass.

Photo: Kjell Andersson

by which it is formed. Charcoal is inert, and does not easily degrade.
In fact, archeologists find pieces of charcoal in old dwellings that are thousands of years old. Yet, no one would doubt that charcoal is a biofuel. In fact, it is the dominant biofuel in many societies. More than 95 percent of all cooking in Monrovia, the capital of Liberia with a million inhabitants, is based on charcoal. The Swedish iron production for centuries was based on charcoal produced from the Swedish forests.

Biomass for energy can be anything from microorganisms like algae to full-grown trees. Sunlight, nutrients and water are the prerequisites.

Photo: Kjell Andersson

Plastics on the other hand will degrade when attacked by the ultraviolet rays from the sun, despite the fact that they are made from fossil oil. Many other products made from fossil fuel based chemicals are also biodegradable, and this of course should not negate their fossil origin.

Another definition used in the academic world reads like this:

"Bioenergy is energy derived from materials created under ongoing biological processes – as compared to fossil energy, which is derived from biological material created under earlier periods of the earth's history".

The problem within this definition is simply a lack of quantification. One has to define what is meant by "earlier periods of the earth's history". Do we put the limit 500 years ago, or one million years ago? And how dead or old can the material be and still be considered a part of an "ongoing process". Once again – how do we classify a peat bog that is still growing?

Biomass and biofuels

Perhaps a more logical approach should be to describe biomass as raw material taken from nature or forestry, agriculture or fishery. It is usually a traditional plant matter, but can also be animal matter, algae or fungi.

The biomass can be used as, and converted to, different fuels, biofuels. These fuels can be unrefined and refined. They can be solid, liquid, or gaseous.

The line between unrefined and refined can be difficult to draw. Does refining include all kinds of preparation (milling, crushing, chipping, etc.) or does it require a chemical or thermal process?

Unrefined solid biofuels are: firewood, woodchips, bark and sawdust.

Examples of refined solid biofuels are: pellets, briquettes, wood powder, and charcoal.

Liquid biofuels are: bioethanol, biomethanol, biobutanol, biodiesel (FAME, HVO, FT-diesel), biooil, bio-DME (preassurised), pyrolysis oil,

Gaseous biofuels are: biogas, biomethane, bio-DME (at atmospheric pressure).

INTERNATIONAL PERSPECTIVE AND CONCLUDING REMARKS

Photo: iStockphoto

14.

A European perspective

The European Union in 2009 adopted a combined energy and climate policy with specific targets for 2020. These targets are:

- 20 percent renewable energy in 2020, as a share of the total energy use.
- 20 percent increased energy efficiency, compared to 2005
- 20 percent lower climate gas emissions, compared to 1990.
- 10 percent renewable energy in the transport sector.

The renewable energy goal is specified in the renewable energy directive, and the targets are different for the different member states, depending on the level in 2005, and the economic levels. The directive also specifies criteria for sustainability for liquid biofuels. The target for renewable energy in the transport sector is the same in all member states. The greenhouse gas target is specified for the emission trading sector for all of EU, and for other sectors for the individual member states.

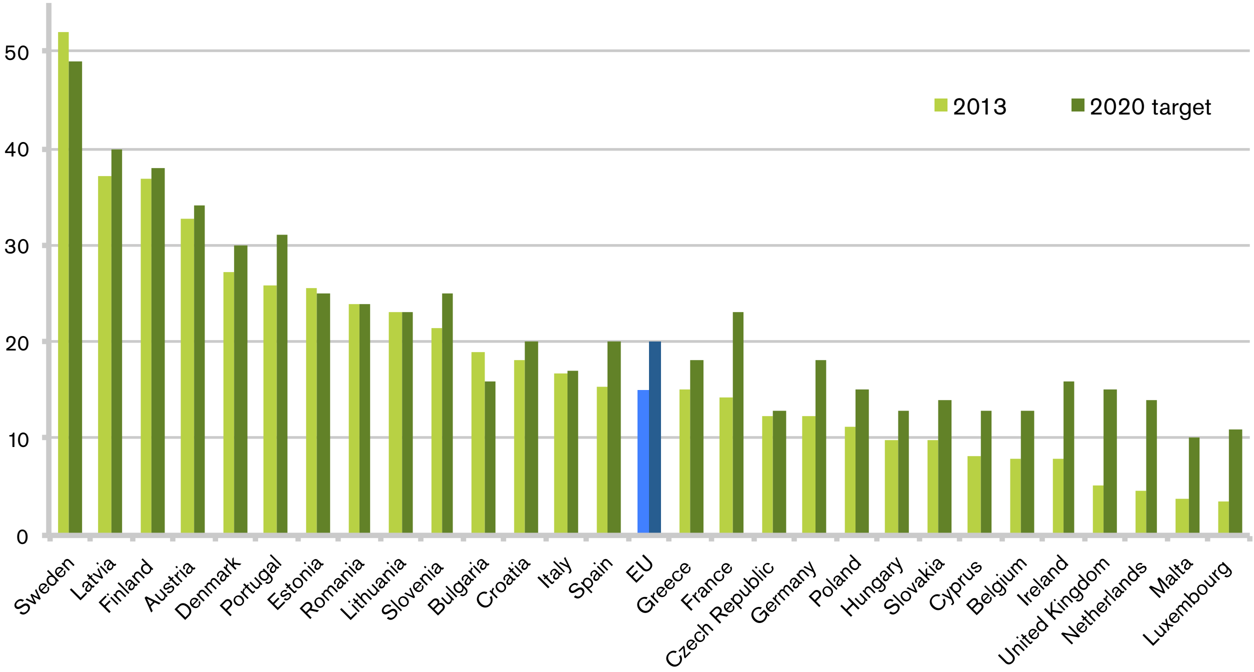
The renewable energy targets for 2020 will probably be overreached according to the national action plans submitted by the member states.

Looking ahead, the EU is developing a strategy to drastically reduce greenhouse gas emissions by 2050. The EU, since 1996, has adopted a goal to limit global warming to 2 degrees Celsius increased average surface temperature. To reach this goal industrial countries need to reduce emissions by at least 80 percent by 2050.

The national action plans show that bioenergy will account for a major part of the increase of renewable energy until 2020.

To reach these targets, the EU member states must introduce efficient incentives in line with the market forces. The proposal for a new energy tax directive includes such incentives – a common minimum carbon tax and a common minimum energy tax.

In October 2014 the EU heads of state and governments agreed on new climate and energy targets for 2030. These targets include a cut in greenhouse gas emissions of 40 percent compared to 1990, an EU-wide target for renewable energy of 27 percent, and an energy efficiency target of 27 percent. No specific target was set for renewable transport fuels.



Sweden reaching EU targets ahead of time

In the Renewable Energy Directive (RED), adopted in 2009, the EU set up 2020 targets for renewable energy for the individual member states, and set a common 10 percent sub-target for renewable energy in transport, the same for all countries.

The 2020 target for renewable energy for Sweden was set to 49 percent, but Swedish parliament decided to raise the target to 50 percent. At the outset Sweden already had a larger share of renewable energy than any other EU member state, thanks to hydropower and bioenergy. The energy minister at the time stated that Sweden had an ambitious and difficult task to reach this target. But the minister was wrong. Sweden reached the 2020 target already in 2012, eight years ahead of time. A major reason was the continued growth in bioenergy deployment.

Sweden also reached the sub-target for the transport sector ahead of time. This target was also reached in 2012. In 2014, it was already 18.7 percent, following the calculation methods prescribed in RED, which includes double

SHARE OF ENERGY FROM RENEWABLE SOURCES IN THE EU MEMBER STATES, 2013

(Percent of gross final energy consumption)

Sweden is the EU member state with the highest share of renewable energy, and one of three EU member states that in 2013 have reached the EU renewable energy target for 2020. The other two being Estonia and Bulgaria. The blue staples show the renewable share for the EU as a whole. The numbers are percentages of renewable energy as a share of final energy consumption.

Source: Eurostat, ec.europa.eu/eurostat

counting for waste and cellulose based biofuels. The real number was 12 percent, also far ahead of the EU target.

Both for renewables in general, and for renewables in the transport sector, a major explanation for the success in reaching the targets was the large use of bioenergy, and the clear incentives pushing the market: carbon taxation of fossil fuels and tax exemption for biofuels in all sectors of the economy.

When the EU targets were decided in 2009 it was often said that it would be difficult for a country like Sweden that already had a large share of renewable energy to further expand this use. The suggestion was that other countries, with low deployment of renewables, would have more room for increases. It turned out to be the other way around. Sweden already had a large number of companies working with renewable energy and a market for renewable technologies and fuels. The further growth was easier than in many other countries where these technologies were new and where the fossil fuel lobbies were stronger.

Stemwood used for bioenergy is often unsuitable for industrial use, like these rotten or half-rotten logs.

Photo: Kjell Andersson

Looking at the list of EU member states and their share of renewable energy, it is obvious that countries with a large forestry sector and rich bioenergy resources have been most successful in reaching high levels of renewable energy utilisation, and will reach the EU targets. Countries with smaller bioenergy resources are struggling to reach these targets.

Critical views in the EU

In recent years, European environmental organisations have become increasingly critical of the growth of bioenergy in the EU. Likewise, many politicians have worried about the negative impacts from an increased use of biofuels. A result of this is reflected in the new directive putting a cap on the use of crop-based biofuels in the EU. Some also doubt the climate neutrality of bioenergy systems, and some even demand a general cap on all biomass use for energy in the EU.

There are also demands for regulation of the use of biomass raw materials. One view is that the use should be regulated according to the cascading principle, the same way as waste is handled. Another demand is that it should be prohibited to use roundwood (stem wood) for energy purposes.

Cascading use means that a resource, like wood, is first used for a high value purpose for products, later reused or recycled, and finally used for energy recovery, when no other options are available. This principle makes sense, but is taken care of on the market. To regulate the use of raw materials from government authorities or through EU directives does, on the other hand, not make sense. It is a kind of planned economy.

Roundwood is in general used as saw logs, as veneer logs, and for pulpwood. The sawmills and pulp factories pay for the wood they want. But marginal quantities of roundwood that are not in demand can be used for energy. It may be wood from unwanted species, partly rotten wood, charred or splinted wood, small trees from thinnings, etc.

In southern U.S., plantations of fast growing pines were established to supply pulp factories with wood. Due to changing demand and other factors, some of these industries have closed down. The trees at these plantations can be used to produce pellets to substitute coal and other fossil fuels.

To regulate the use of roundwood for energy is not feasible, and would interfere with the general principles of free trade.

Untapped resources in Europe

Within EU countries there are at least 10 million hectares of abandoned farmland. Between the Ural mountains and the Atlantic, unused or underused areas of arable land total around 60 million hectares. The population of Europe is stagnating, and European farming produces a surplus of food. All of these factors imply that there is room for a large increase in production of energy crops on farmland.

In European forestry as well, there is room for higher production of biomass for energy. Almost all the member states have positive figures for LULUCF (land use, land use change and forestry), with a positive increment in the forests (higher growth than fellings). Be that as it may, forest ownership is fragmented in many countries, making it difficult to mobilise the forest resources.

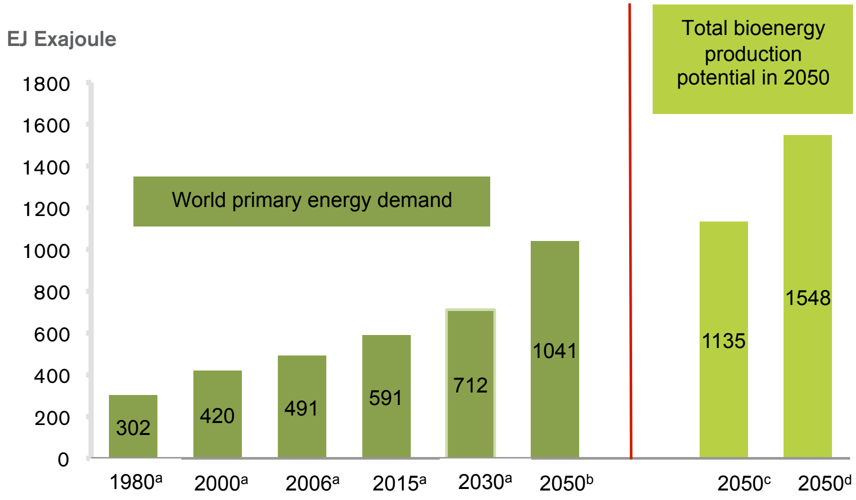
To summarise, the production of biomass for energy has the potential to increase massively in Europe compared to the current situation. This will boost employment and contribute to rural development all over the continent.

Jatropha is one of the energy crops given much attention in todays research.

Photo: Karin Haara

BIOENERGY POTENTIAL 2050 ➤

In a report from Swedish University of Agricultural Sciences the global potentials for bioenergy were estimated to 1,135–1,548 ExaJoule, enough to supply all global energy needs. The report is available from World Bioenergy Association, www.worldbioenergy.org.



A global perspective

Bioenergy is becoming more and more globalised. Pellets, wood chips and biofuels are traded between countries and continents. The refined fuels are becoming commodities, just like the traditional fossil fuels. Soon we will see these fuels on the commodity exchanges and we will see more indices and trade on spotmarkets and in futures.

Likewise, technology, experience and know-how need to be disseminated following the patterns for trade in more mature global industries like the forest-based industries, the food industry, and traditional energy.

The World Bioenergy Association (WBA) asked SLU, the Swedish Agricultural University, to compile a report on global potentials for bioenergy. Their findings suggest that bioenergy has the potential to meet the total global demand for energy in 2050, based on a scenario with high ambitions for energy efficiency. In reality, the picture will be more diverse – there will also be wind, hydro, solar, geothermal and ocean energy. There is no doubt that renew-ables together have the capacity to supply the worlds total energy demands. Moreover, this shift in energy production is vital if the world shall succeed in reducing the greenhouse gas emissions enough to limit global warming to a 2 °C increase.

Bioenergy is particularly promising to the developing countries in Africa and Latin America. These countries have abundant untapped natural resources that can be used for food, feed and bioenergy production. The average yields in African farming are currently at only one fifth or less of the yields in farming in the industrial countries. With increased investments in modern technology, improved breeds, fertilisation, and education, the yields will increase considerably and give more income to farmers as well as more affordable food. With such development there will be room both for food production and energy crops.

Bioenergy will increase security of supply, as biofuels will lessen dependence on imported fossil fuels for countries with no fossil energy resources. More than a hundred countries have the right conditions for growing sugar cane and producing ethanol. Most countries along the equator can produce palm oil, the most productive oil crop.

The conditions for producing biomass for energy are particularly favourable in the tropical countries. The growing season is all year around, compared to temperate regions where the winter season limits production. Most countries have good water resources, and the production can be rain-fed. In other regions irrigation is possible. Trees grow to maturity in 7–10 years in tropical plantations, compared to 25–100 years in temperate regions and boreal forests. Eucalyptus and tropical pine are two examples of highly productive species for cellulosic biomass. Sugar cane, oil palm and corn are all well-known and highly productive species for sugar and starch based biofuels. But there are numerous other crops that today are being investigated by scientists as energy crops suitable for developing countries in tropical and subtropical regions, like jatropha, tropical sugar beet, tapioca, bamboo, and many others.

Sugar cane can produce more than 100 tonnes per hectare.

Photo: Kjell Andersson

Concluding remarks

Sweden has managed to increase its use of bioenergy with 100 TWh (almost 10 mtoe, million tonnes of oil equivalent) during the last 40 years. The transition has accelerated over time, and during the last decade the growth of the sector has been 3–4 TWh per year.

Bioenergy has gone from constituting approximately one-tenth of Sweden's energy use to one-third, from 10 to 34 percent of final energy use today. Bioenergy has become the leading energy source.

The development has never been hampered by lack of supply. All this time, it has been possible to mobilise new resources of biomass for energy, and expand the raw material base. Most of the biomass is derived from forestry, and so far the potentials in agriculture have only been marginally tapped.

Sweden's parliament has been consistent in its support for bioenergy, passing strong general incentives like the carbon dioxide tax and the green certificates, usually with broad majority.

Photo: Melker Dahlstrand

The cold Swedish climate means a relatively high energy demand. The climate is also a strong driving force for energy efficiency measures.

Photo: Kjell Andersson

The development of bioenergy was driven by these factors:

» A strong political will do decrease the dependency of imported fossil fuels, mainly oil. This was a leading theme from politicians from the oil crisis in 1973 up to Prime minister Persson's Oil independence commission in 2006.

» A strong political will to strive for a better environment, like early policies to promote district heating, policies to find alternatives to nuclear power, policies in the 1980s to reduce sulphur emissions, and today's ambitions to cut climate gas emissions.

» Strong and relatively consistent political support. In the early stages as direct support to investments, and from around 1990 with general incentives, where the carbon tax has been the most potent measure.

» Developments in the fuel market like the two oil crises, and from 2005 and onwards the big price hike in oil.

» Access to competence and entrepreneurial skill, which led to fast increases in efficiency and lower costs of biomass supply, in spite of rapid market growth.

Bioenergy, as an industry, has grown because the right conditions were created to expand the market and make it profitable for companies and private actors to deliver bioenergy to the market.

Research and development has contributed heavily to the advancement of the industry, and has given the bioenergy sector good arguments for demanding political support, e. g. research showing the large potentials of bioenergy. Technical development has taken place mainly within the industry itself, but there are also examples of research having been undertaken at the universities, which has had profound influence on the developments, like salix/SRC, biomass gasification and torrefaction research.

Leading individuals with vision have played a vital role. Among them are researchers, private entrepreneurs, politicians, governmental officials and people working in large energy and forestry companies. Many of these individuals have been active in Svebio.

Svebio has played an active role as a promotor of bioenergy, spreading information, arranging conferences, writing position papers and articles in newspapers, talking with politicians, publishing magazines, etc.

Hopefully the Swedish experience can be an inspiration to others.

ABOUT SWEDEN

Sweden has a population of 9.8 million people. 2 million of these live in the greater Stockholm area. The land area is around 450 000 square kilometres (45 million hectares, or 174 000 square miles).

Sweden is a member of the European Union since 1995.

◀ Photo: Kjell Andersson

LAND USE

Farmland 3.3 million hectares

» Fields 2.7 million hectares, meadows, etc 0.6 million hectares. Grain like wheat, barley and oats are grown on 1.2 million hectares. 0.9 million hectares are used for hey, silage and grazing. Other crops are sugar beets, rape, potatoes and peas. 15 000 hectares are planted with salix – fast growing willows.

Forest 23 million hectares

» More than 52 percent of the total area, and 59 percent of the land area is covered with forest. Only about 2 percent of the forest is protected as natural reserves. But all forestry has to adhere to environmental regulations.

Open bogs 4.6 million hectares

» The total area with peat is 10 million hectares, of which 6.4 million hectares have a peat cover of more than 30 cm. Much of the peat area is planted with forest, and some areas have been drained for farming.

Built up areas (houses, roads, etc.) 1.3 million hectares

Lakes 4.0 million hectares

» There are more than 100 000 lakes, most of them small, but several large ones.

The rest is primarily open land in the mountain region, other mountains and rocks.

FOR MORE INFORMATION, CONTACT :

Svebio

Svebio (Svenska Bioenergiföreningen) – The Swedish Bioenergy Association – was founded in 1980. Svebio has around 300 member companies engaged in the bioenergy supply chain. Svebio publishes a monthly newsletter, one national magazine, Bioenergi (6 issues per year), both in Swedish, and Bioenergy International, with 7 issues per year in English, and with several editions in other languages. Svebio also organises conferences, both national and international. **www.svebio.se**

AEBIOM

AEBIOM was founded in 1990, and is the European Biomass Association with 36 national member organisations throughout Europe. AEBIOM , with its main office in Brussels, represents around 4 000 companies, organisations, research institutions and individuals engaged in the bioenergy sector in Europe. **www.aebiom.org**

World Bioenergy Assocation

World Bioenergy Association was formed in 2008, and has its office in Stockholm. It is the global voice of the bioenergy sector. Among the members are regional and national bioenergy organisations, companies, institutions, and individuals who want to promote bioenergy. WBA joins with the global wind, solar, hydro and geothermal organisations in the International Renewable Energy Alliance. **www.worldbioenergy.org**

Swedish Energy Agency

The Swedish Energy Agency is a government agency for national energy policy issues. The Agency has around 350 employees. Their mission is to promote the development of Sweden's energy system so that it will become ecologically and economically sustainable. This means that energy must be available at competitive prices and that energy generation must make the least possible impact on people and the environment. **www.energimyndigheten.se**

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