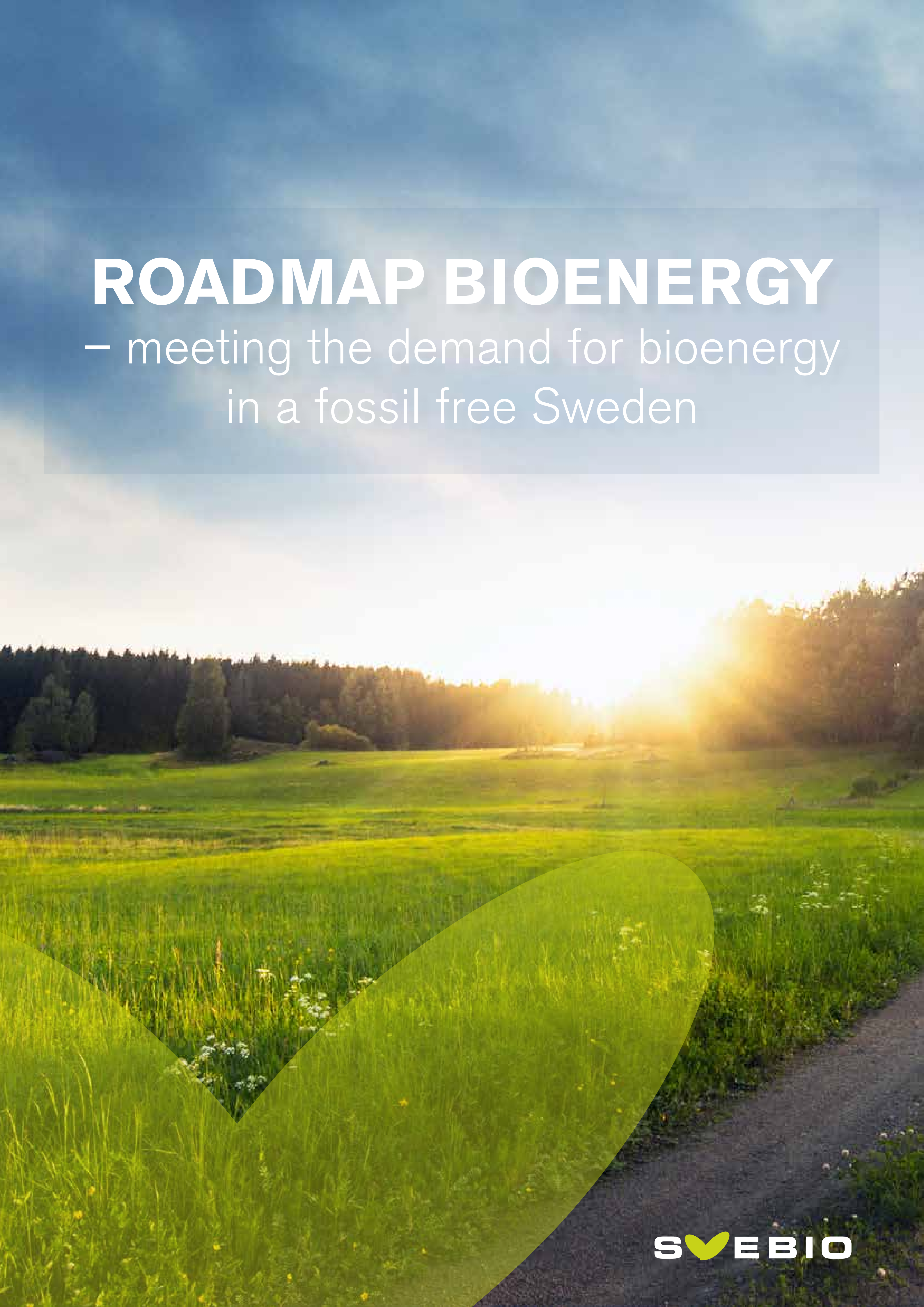
ROADMAP BIOENERGY

– meeting the demand for bioenergy in a fossil free Sweden



SVEBIO

FOREWORD. Sweden's high share of bioenergy will increase – your country can have a similar development!

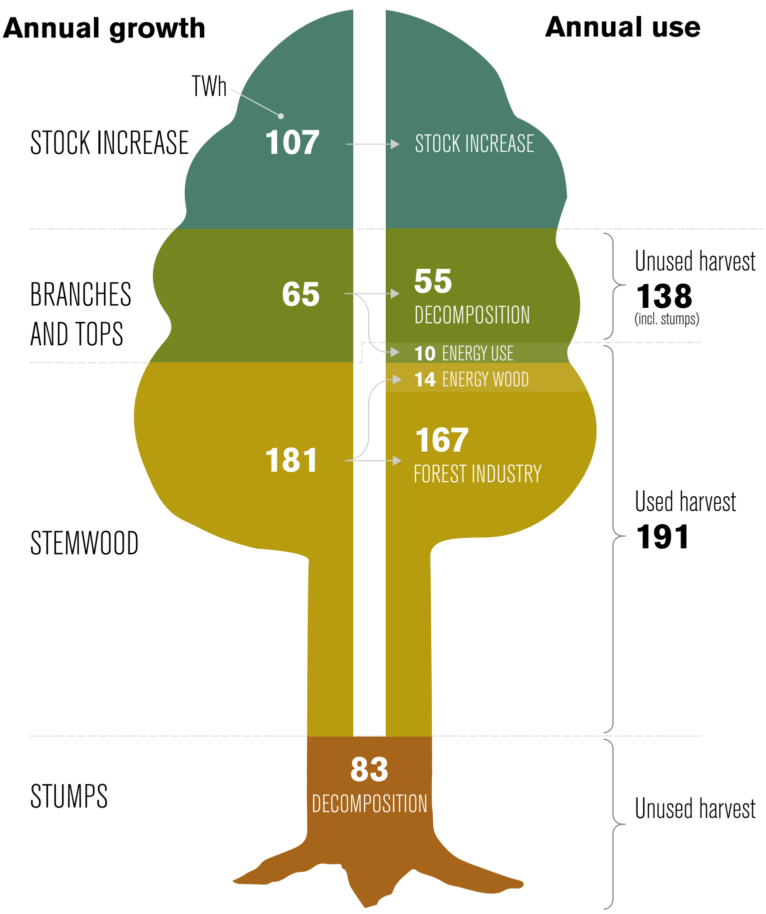
Bioenergy is Sweden's largest source of energy and accounts for 38 per cent of Sweden's energy use today. The use of bioenergy has more than doubled since the beginning of the 1990s. We can double again, until 2045. Between 2000 and 2017, the use of bioenergy increased by 3.5 TWh per year. This report, Roadmap Bioenergy, shows that we can continue at the same pace for the next 25 years.

Within the framework of the Government's initiative "Fossil free Sweden", the various sectors of the Swedish business community have produced an impressive set of roadmaps for a fossil free Sweden. The roadmaps show that there are technical solutions to replace virtually all use of fossil fuels until 2045. Business organizations and other actors have identified two main solutions to replace fossil fuels and reduce climate impact: electrification and bioenergy. Based on the requests in these roadmaps, about 50 TWh more electricity and 100 TWh more bioenergy will be needed.

You may believe that Sweden is unique and that this development is possible only in Sweden. But I would say: this can be done in every country!

Obviously, the Swedish forest and the forest industry make it easier but the reason why we have a large share of bioenergy is mainly because of our high carbon tax and the ability to create a market-based demand for renewable energy.

» FIG. 1 **YEARLY FOREST BALANCE IN ENERGY TERMS (TWh)**



Almost every country has large volumes of available biomass, untapped waste streams from agriculture and food industry, often also inefficient energy use. With an appropriate policy, a steady shift from fossils can be done in every country. Both through more efficient energy use, as combined heat and power instead of condense power production, and through increased use of bioenergy and other renewables.

In our Roadmap Bioenergy, we analyze the potentials for bioenergy with domestic resources in Sweden. But even though the bioenergy potentials exist in Sweden, it is not obvious that these opportunities will be realized. Producing biofuels for transport from Swedish biomass resources is today somewhat more expensive than using biomass resources available on the world market. If Swedish biomass resources are to be used, policy and market development is needed both in Sweden and on a global level.

We are looking forward to a very interesting development in this sector and to explore the potential of replacing the of fossil energy with bioenergy and other renewables!

Finally, I really would like to thank our colleague Kjell Andersson the main author, for his eminent work with this Roadmap Bioenergy!

Gustav Melin
CEO, Svebio

Stockholm,
24 March 2020

The figure shows yearly growth on productive forest land in Sweden. The total growth is 436 TWh. Large volumes of stumps, branches and tops are left in the forest to decompose, currently the equivalent of 138 TWh per year.

According to the report around 30 per cent of this volume could, in the near future, be better used as bioenergy, whereas the main part would remain in the forest to maintain biodiversity.

Source: IRENA report based on data from Swedish Forest Inventory 2015.

CONTENT

SUMMARY

– How we can supply 250 TWh bioenergy in 25 years

We have the potential to produce and use 250 TWh of biomass for energy purposes in Sweden in 25 years, which is about a doubling compared to the current use of domestically produced biomass.

The volumes are sufficient to meet the needs reported in the roadmaps produced by “Fossil-free Sweden” as well as the needs that exist to decarbonize domestic transportation in Sweden in accordance with the Parliament's objectives.

The biomass currently used for energy purposes, as well as the additional biomass, consists mainly of by-products, residues and waste from forestry and agriculture and the industries that process forestry and agricultural raw materials. In addition, significant volumes of biogenic residual waste from society are used.

The greatest potentials for increased supply are through:

» Better utilization of harvesting residues in forestry from tops, branches and stumps.

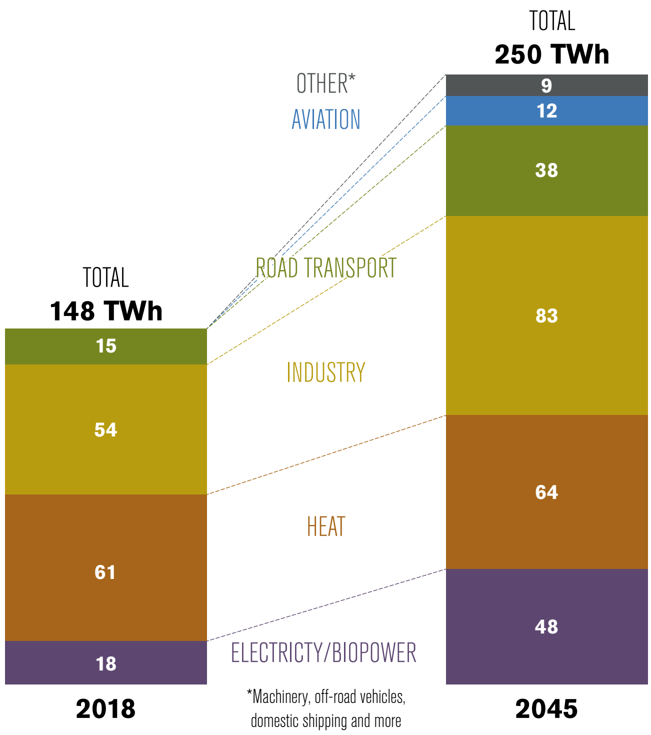
» Increased cultivation of energy crops on arable land and recovery of residues in agriculture.

Comprehensive sustainability criteria are now being introduced for all types of bioenergy.

The Swedish forest-bioenergy system provides a very significant climate benefit with a positive climate effect of around 90 million tonnes of CO_2 per year. Utilization of bio-CCS (bioenergy + carbon dioxide capture and storage) at major combustion plants can provide an additional climate benefit of 30 million tonnes of CO_2. Increased production of biomass means increased absorption of CO_2 and increased opportunities to replace fossil fuels and thus reduce fossil CO_2. emissions.

An increased use of bioenergy has positive effects on security of supply as well, even for defense preparedness and for the Swedish economy, not least by creating jobs throughout the country.

» FIG. 2 BIOENERGY SUPPLY 2018 AND 2045 (TWh)



The current use of bioenergy and projected long-term supply towards 2045. Bioenergy supply increases with 102 TWh in 25 years. Supply of 48 TWh biomass leads to 40 TWh electricity production.

POTENTIAL FOR INCREASED SUPPLY OF BIOENERGY

ORIGIN:	CURRENT DOMESTIC USE (TWh)	CURRENT USE, IMPORT (TWh)	POTENTIAL INCREASE, NEAR FUTURE (TWh)	POTENTIAL INCREASE, LONG-TERM (TWh)
FOREST	102	2*	42	74
AGRICULTURE	2	10**	22	54
AQUATIC	0	0	0	1
PEAT	1	0	5	5
WASTE	13	18***	6	6
MARGINAL BIOMASS	-	-	7	7
TOTAL	118	30	82	147

The table shows today's use of bioenergy and the long-term potential. Note that agriculture can become a large supplier of energy in the future. The land that is not longer needed for food production should be used for energy crops for biomass and biofuels.

** The import of forest fuels consists of net import of pellets and limited import of wood chips, mainly from the Baltics.*

*** The import mainly consists of raw material for biofuels, and biofuels, and of bio-oil.*

**** The import of waste is made up of municipal waste and recycled wood for heat and electricity production, and waste-based HVO and bio-oils. Note that some of this waste is of fossil origin, like plastics. The share of fossil waste will decrease over time.*

1. INTRODUCTION

The Swedish Energy Commission in its report 2017 set the target for 100 per cent renewable electricity production in 2040. Svebio believes that ***a Swedish 100 per cent fossil-free and renewable energy system*** can be achieved by 2040 or shortly thereafter, which also includes heating, transport and industry.

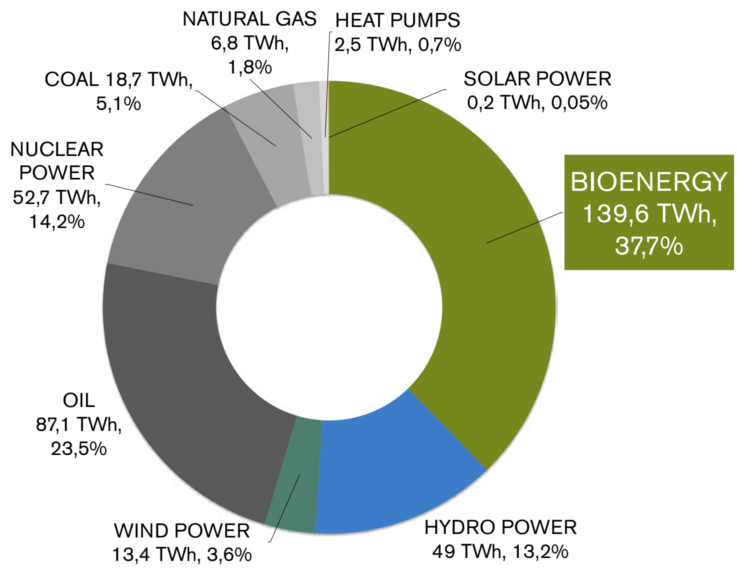
The heating sector in Sweden is basically fossil-free today. The biggest challenges are in the transport sector and in the industry. Bioenergy can make significant contributions in both sectors. Within the framework of a 100 per cent renewable electricity production, a considerable volume of base load capacity will be required. Here biopower can play an important role. Biopower can also strengthen the capacity of the electricity networks regionally.

Our report shows that about a quarter of the additional need for bioenergy can come from increased biopower production, a quarter from industry, and about half from the increased need for liquid fuels for the transport sector, including aviation, machinery and off-road vehicles.

In 2018, bioenergy accounted for 35 per cent of the Swedish energy use.

The need for bioenergy could almost double from today's approximately 150 TWh (including waste) to around 250 - 270 TWh. With an unchanged energy consumption of around 370 TWh, bioenergy in 2045 can account for 70 per cent of Swedish energy supply.

» FIG. 4 **FINAL ENERGI CONSUMPTION IN SWEDEN 2018**

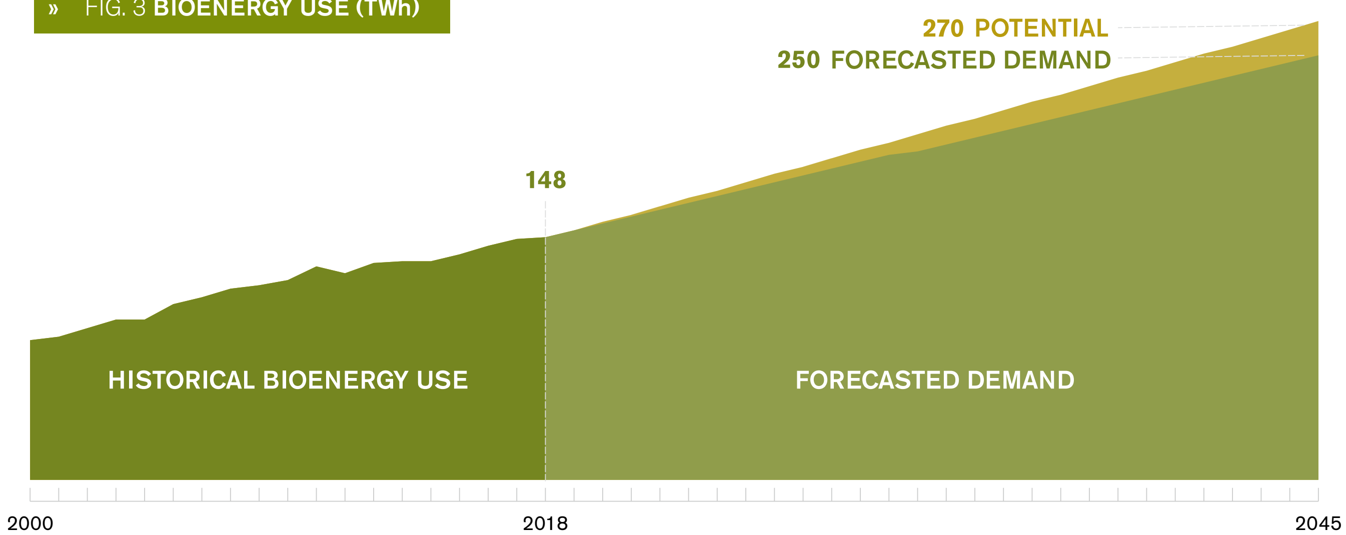


Source: Svebio, based on statistics from Swedish Energy Agency

2045 is also the year when we should have achieved a fossil-free economy. Remaining energy supply consists mainly of electricity from hydropower and wind power, as well as contributions from solar energy and heat pumps.

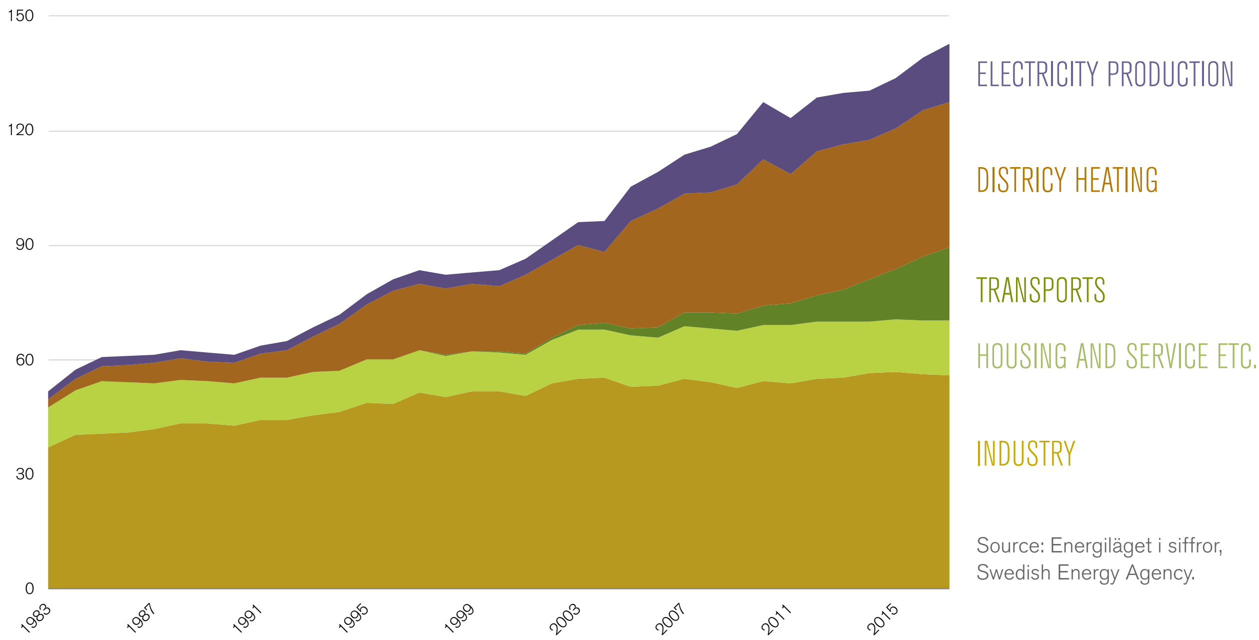
Our estimation is that the increased supply of bioenergy can occur mainly within domestic production, but that there will also be an increased trade.

» FIG. 3 **BIOENERGY USE (TWh)**



The chart shows total energy supply (delivered) of bioenergy in Sweden, development since 2000 and forecast for demand until 2045, and potential for increased supply.

» FIG. 5 **BIOENERGY USE PER SECTOR 1983 - 2017 (TWh)**



Source: Energiläget i siffror, Swedish Energy Agency.

The use of bioenergy in Sweden has increased steadily over the past 35 years. The use has more than doubled since 1990.

1.1 THE DEVELOPMENT UNTIL TODAY

The use of bioenergy has increased very rapidly over the last thirty years.

From 1983 to 2017, the use of bioenergy increased-from 51 TWh to 143 TWh according to the Swedish Energy Agency. This corresponds to about 3 TWh peryear. The increase has been relatively uniform over time, but it has occurred in different sectors during different time periods.

Industrial use of bioenergy, primarily in the forestindustry, increased until year 2000, but also in later years, we have seen a switch of fuels, from fossil fuels to the industries own by-products.

The carbon dioxide tax introduced in 1991 led to a rapid increase in use of biofuels for district heating. But the increase slowed down around 2010 as the district heating market stopped growing.

The introduction of the electricity certificate system in 2003 increased the use of biofuels forelectricity generation, both in cogeneration plants in district heating and in turbines in the forest industry. In recent years, we have seen an increased use of biofuels for transport. The main incentive was tax exemption for renewable transport fuels, which made biofuels competitive with diesel and petrol.

2. POTENTIALS FOR INCREASED USE

2.1 USE - ELECTRICITY PRODUCTION

When an ever-increasing proportion of variable electricity production is introduced to the electricity grids, a 100 per cent renewable system for electricity production needs base load capacity and regulating power to provide guaranteed power supply during all hours of the year.

Increased local electricity generation through cogeneration can guarantee power supply, especially in larger cities, where we see a lack of generation and insufficient capacity in the electricity grids today. In all these cases, biopower can play a crucial role.

Biopower is the only renewable form of electricity generation that can be located in the cities and at the same time offer dispensable production during the cold season and during dark hours of the day.

Biopower also benefits from the fact that the energy is stored in the fuel, at a low cost. Through electricity production close to the users, both in population centres and in industry, the expansion of biopower production does not require major investments in electricity grids.

Svebio's biopower platform (2016)[1] shows that it is possible to increase biopower capacity by 10 GW with an annual production of 40 TWh. This can be compared to today's production of about 13 TWh biopower (including electricity from waste and peat). The additional biopower production will mainly be based on existing heat loads in district heating grids and industries, which gives an energy efficiency of 90 per cent or more based on added fuel. Therefore, an increase of 27 TWh requires a fuel consumption of about 30 TWh.

A sharp increase in biopower production requires an adjustment of the pricing on electricity for the costs and values that different types of electricity productions contribute to. In this way, biopower can be compensated for its guaranteed power and dispensability.

2.2 USE – HEATING OF BUILDINGS

Residential heating is today done with very little input of fossil fuels. According to the “Roadmap: The heating sector” from Fossil-free Sweden, the ambition is to completely stop using fossil fuels by 2030, with the exception of incineration of fossil plastics in waste in some heat plants[2].

In addition, there is a potential for small-scale use of bioenergy to cut power demand peaks in the heating of family homes and to replace electric heating, in accordance with the Energy Commission's proposals 2017. Uncertainty mainly exists with regard to the total need for district heating and the remaining opportunities to expand district heating networks. The forecasts are not consistent.

District heating in Sweden is to a large extent based on bioenergy and biogenic waste already, about 70 per cent, including residual heat from bio-based industry. If all remaining use of coal, natural gas and oil for district heating production is replaced with bioenergy, we need an additional 2.8 TWh biomass fuels for district heating.

Installing pellet stoves in 50 per cent of all family homes that currently use electricity for heating would require about 0.5 TWh of pellets[3].

Photo: Scandbio

A modern pellet stove can provide a large part of the heat demand in a villa, reduce the need for electrical heating and reduce the power requirement.

1. Svebio, Ett 100 procent förnybart elsystem kräver en betydande andel biokraft, rapport från Biokraftplattformen.

2. Färdplan för fossilfri konkurrenskraft Uppvärmningsbranschen.
3. PelletsFörbundets pelletsvision, www.pelletsforbundet.se


Photo: Niclas Noord

The greenhouse industry has largely replaced fossil fuel oil with biofuels. Here, a pellet silo is installed at one of Svenska Skogsplantor's greenhouses.

2.3 USE – HEAT AND PROCESSES IN INDUSTRY

The restructuring of the industry, with the phasing out of fossil fuels, leads to sharply increased demand for bioenergy. Already today, bioenergy is the largest source of energy in the Swedish industry, but the use of bioenergy is mainly taking place in the forest industry. When phasing out fossil fuels in other industries, large quantities of bioenergy will also be needed within these. A variety of different solid, gaseous, and liquid biofuels, will be required, with varying energy quality and refinement.

Two ambitious studies have been conducted on how the conversion to a fossil-free industry can take place. One was carried out by "Fossil-free Sweden" with a number of roadmaps for different industries, with energy requirements summarized in a report from Sweco. Another study was conducted by the Swedish Academy of Engineering Sciences, IVA.

The two studies show an increased need for bioenergy at approximately the same level. The Sweco report[4] gives a span of 21 - 26 TWh, while the IVA report gives a span of 18 - 32 TWh. For most industrial sectors, the two studies have similar assessments.

The greatest uncertainty in the IVA report[5] concerns the chemical industry, where the question is whether it is possible or probable that large volumes of biobased raw material can be supplied, for example in the form of biogas. In both reports, it is expected that the steel industry will primarily switch to a hydrogen-based process, assuming the Hybrit project will be technically and financially successful. None of the analysis have expected to use bio-based carbon instead of fossil carbon in blast furnaces. However, bioenergy is used for other processes, such as iron powder production (the Höganäs process). The Hybrit process is reported to require an input of 17 TWh of electricity.

A difference between the reports is that the Sweco report is based on the published roadmaps from Fossil-free Sweden, while IVA has made an assessment for the entire industry, which means that there is also a need for "other industry", of 2.1 TWh bioenergy.

Svebio's assessment of the additional amount of biomass will be as follows:

TABLE 1, **INCREASED USE OF BIOENERGY PER SECTOR/INDUSTRY**

INDUSTRY:	BIOENERGY, BIOMASS (TWh)
STEEL INDUSTRY, EXCL. HYBRIT	4 – 5
MINES AND MINERAL INDUSTRY	2 – 2,5
METAL INDUSTRY	1 - 2
CEMENT	4,5
REFINERIES	1,5
CHEMICAL INDUSTRY	8 - 9
FOREST INDUSTRY	2,4
OTHER INDUSTRY	2,1
TOTAL	25 – 28,5

Since the two reports were based on the industry's own assessments, or produced in consultation with the industries, there is high credibility for the choice of energy carriers and for the specified levels.

4. Sweco, Klimatneutral konkurrenskraft – kvantifiering av åtgärder i klimatfärdplaner.
5. IVA, Så klarar svensk industri klimatmålen – en delrapport från IVA-projektet Vägval för klimatet.

As far as the chemical industry is concerned, we have based our assessment on the Sweco report, and the IVA report concerning "other industries". Of the fuel volume, approximately 12 TWh will be solid fuels, primarily for cement, forestry, mining and minerals, steel and other industries, while the need for biogas of 11 TWh mainly applies to the chemical and steel industries. The need for liquid biofuels is limited to a few terawatt hours. The balance between electricity and fuels (which must be renewable biofuels) will ultimately be determined by the economic conditions for various possible alternatives.

If the Hybrit process does not prove successful, but is replaced by a process based on biocoal (charcoal), the need for biomass increases considerably. The current consumption of coal/coke in the iron and steel industry is around 14 TWh. Replacing all fossil carbon with biochar may require a supply of up to 18 TWh of biomass for biochar.

2.4 USE - TRANSPORT

Uncertainty is greater regarding the development in the transport sector than in other sectors. Primarily, there are differences in assessments when it comes to electrification, but also regarding the possibilities of influencing behaviour and changing the transport system as a whole.

The transport sector is also included in the Sweco report quoted above. Sweco made an up-date of a previous governmental study from 2013 (the FFF study – Fossilfrihet på väg SOU 2013:84). The study included proposals for energy efficiency, renewable fuels, and "development of society and transport modes" (including issues like city planning, changing behavioural patterns, carpooling, etc.). Swecos does not include these changes in society, as very few of them have taken place in the years following the study. But they include the other components, like more efficient cars and gradual electrification. Their conclusion is that Sweden will need 50 TWh of fuels for road transports. Sweco's assumption is that 60 per cent of the cars are fueled with electricity and 40 per cent with biofuels, whereas heavy duty vehicles use 75 per cent biofuels and 25 per cent electricity. This results in a demand for 33.9 TWh of biofuels and 17 TWh of electricity for road transport. Our own assumption is that 75 per cent of the fuels both for heavy duty vehicles and for cars will be biofuels. With this assumption, we will need 37.5 TWh biofuels. Today, the use of biofuels for transport is around 15 – 19 TWh.

When it comes to aviation, Sweco, based on the Roadmap for the aviation industry, expects fossil fuels to be completely replaced by biofuels, and that increased flying is compensated by efficiency improvements. This assumption corresponds to the assumptions made by the study Biojet for aviation (SOU 2019:100). A total fuel change for aviation requires 2 TWh biofuels for domestic flights and 10 TWh biofuels for refuelling of international flights.

In the case of machinery/off-road vehicles, an assumption is made of 30 per cent efficiency improvements, 50 per cent biofuels (biodiesel), 15 per cent electrification and 5 per cent eco-driving. This gives an increased need for biodiesel of 6 - 6.5 TWh. We specify 7 TWh because we do not want to assume behavioural changes.

Machinery/off-road vehicles are primarily tractors and machinery in agriculture, vehicles in construction, in the mining industry, forestry machines, etc.

Domestic shipping (coastal shipping, ferry traffic) consumes about 1.75 TWh and non-electrified railways about 0.2 TWh diesel. We assume that domestic shipping can completely switch to biofuels and that rail diesel can be entirely replaced by biodiesel.

Bunkering for foreign shipping is around 30 TWh, and in this sector there is hardly any alternative to biofuels in the foreseeable future.

2.5 TOTALLY INCREASED USE OF BIOENERGY

The following table shows the increased use of bioenergy for domestic energy supply (incl. Refuelling of foreign flights but excluding bunkering for foreign shipping).

TABLE 2, **INCREASED USE OF BIOMASS**

AREA OF USE:	TODAY'S USE (TWh)	ADDITIONAL USE (TWh)
ELECTRICITY/BIOPOWER	18	30
HEATING	61	3
INDUSTRY	54	25 – 29
STEEL PRODUCTION	0	0 – 18
ROAD TRANSPORT	15	19 – 23
AVIATION	0	12
MACHINERY, OFF-ROAD VEHICLES, DOMESTIC SHIPPING ETC	0	9
SUMMARY	148	98 – 124

3. AVAILABILITY OF BIOMASS FOR ENERGY PURPOSES

The availability of biomass is ultimately determined by the ability of the photosynthesis to bind carbon dioxide using sunlight, water and nutrients. Unlike fossil carbon combustion, which involves the consumption of stored carbon resources, biomass is a renewable carbon resource that is produced continuously and the combustion of biomass is part of the natural carbon cycle between the biosphere and atmosphere.

3.1 BIOENERGY FROM FOREST

The bioenergy used in Sweden today is primarily from the forest, and mainly in the form of by-products from the forest industry, such as bark, shavings and wood chips, but also as harvest residues from felling, such as branches and tops.

A small part of the biomass for energy is harvested as small trees during forest management, from clearing and thinning. A limited volume is stemwood, partly as discarded wood, that cannot be used as raw material for the industry (for example, damaged and rotten wood) and partly as firewood for small-scale use for heating and cooking. There is considerable potential to increase the extraction of biomass from the forest, both as primary fuels from forestry and through better utilization of by-products. In addition, there is unutilized potential from marginal land (see page 16).

The question of the potential for increased harvest has been analyzed in many reports over the years. Documentation was developed by SIMS at the Swedish University of Agricultural Sciences (SLU) as early as the 1990s, and the potentials calculated back then are still largely valid today[6].

The total growth in the productive forests in Sweden in 2015 had a total energy content of 436 TWh. Growth is increasing by about 1 per cent per year (see figure on page 11), which means that the total growth should be around 450 TWh per year today. This up-take of biogenic carbon corresponds to more than the entire Swedish final use of energy, which is around 370 TWh.

This is shown in a compilation of energy flows in Swedish forestry and bioenergy utilization, presented in the report "Bioenergy from boreal forests", by IRENA, the UN Renewable Energy Agency, (see next page)[7].

Photo: Kjell Andersson

During clearings and thinning, large volumes of small trees fall, which could be used as fuel.

Of the total growth on productive forest land of 436 TWh, 329 TWh was harvested. Of this, stemwood accounted for 181 TWh, of which about 14 TWh was used as energy (firewood and discarded wood).

The remainder (148 TWh) was crop residues in the form of tops and branches, stumps and roots where only about 10 TWh of tops and branches were used for energy purposes, while 138 TWh was left in the forest to decompose.

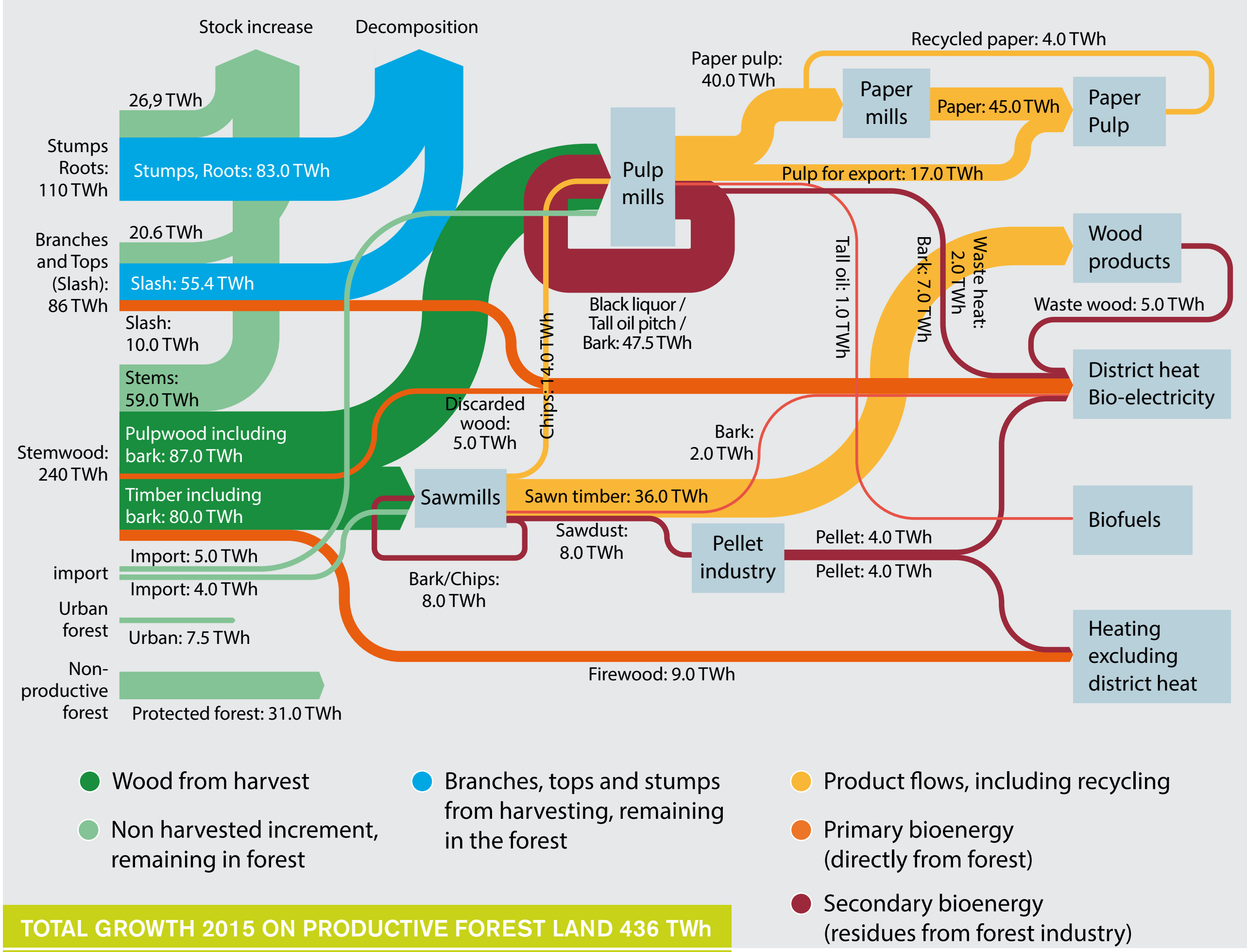
In total, Swedish forest stocks increased by 107 TWh, including 59 TWh stemwood and 48 TWh tops, branches and stumps in growing forests. About half of the timber delivered to the forest industry was used for products such as sawn wood products, pulp and paper, and half was used for energy purposes.

In 2016, Pål Börjesson estimated[8] the potential for increased supply of forest biomass to 24 - 33 TWh in the short term and 36 - 50 TWh in the longer term (2050), with uncertainty intervals of up to 42 TWh and 74 TWh respectively. The uncertainty mainly concerns the potential for increased harvest of tops, branches and stumps.

6. Lönner m fl 1998, Kostnader och tillgänglighet för trädbränslen på medellång sikt, SIMS, Institutionen för Skog-Industri-Marknad Studier rapport nr 51.
7. IRENA och Svebio 2019, Bioenergy from boreal forests: Swedish approach to sustainable wood use.

8. Börjesson 2016, Potential för ökad tillförsel och avsättning av inhemsk biomassa i en växande svensk bioekonomi. Lunds universitet 2016.

» FIG. 6 **FLOW CHART OF THE SWEDISH FOREST-BIOENERGY SYSTEM EXPRESSED AS ENERGY (TWh)**



TOTAL GROWTH 2015 ON PRODUCTIVE FOREST LAND 436 TWh

The values apply to a normal production year around 2015. Based om statistics from the Swedish National Forest Inventory (Riksskogstaxeringen), Statistics Sweden (SCB), Swedish Energy Agency (Energimyndigheten), Swedish Forest Industries Federation (Skogsindustrierna) and others.

Source: Bioenergy from boreal forest, Swedish approach to sustainable wood use. IRENA, International Renewable Energy Agency 2019.

The potential is reduced from the maximum theoretical potential for ecological, technical and economic reasons. The ecological restrictions are partly about considerations for biodiversity and conservation, and partly the impact on soil (nutritional status) and water. Technical and financial constraints are about how much can be harvested with today's technology and what is profitable, for example for transport and economic reasons, size of harvesting areas, etc. Svebio's assessment is that Pål Börjesson's assumptions are cautious and that one can rely on the upper values in the intervals he specifies, including uncertainty intervals, i e 42 TWh in the near future and 74 TWh in the long term. When balancing climate benefit and biodiversity, the climate benefit must weigh strongly.

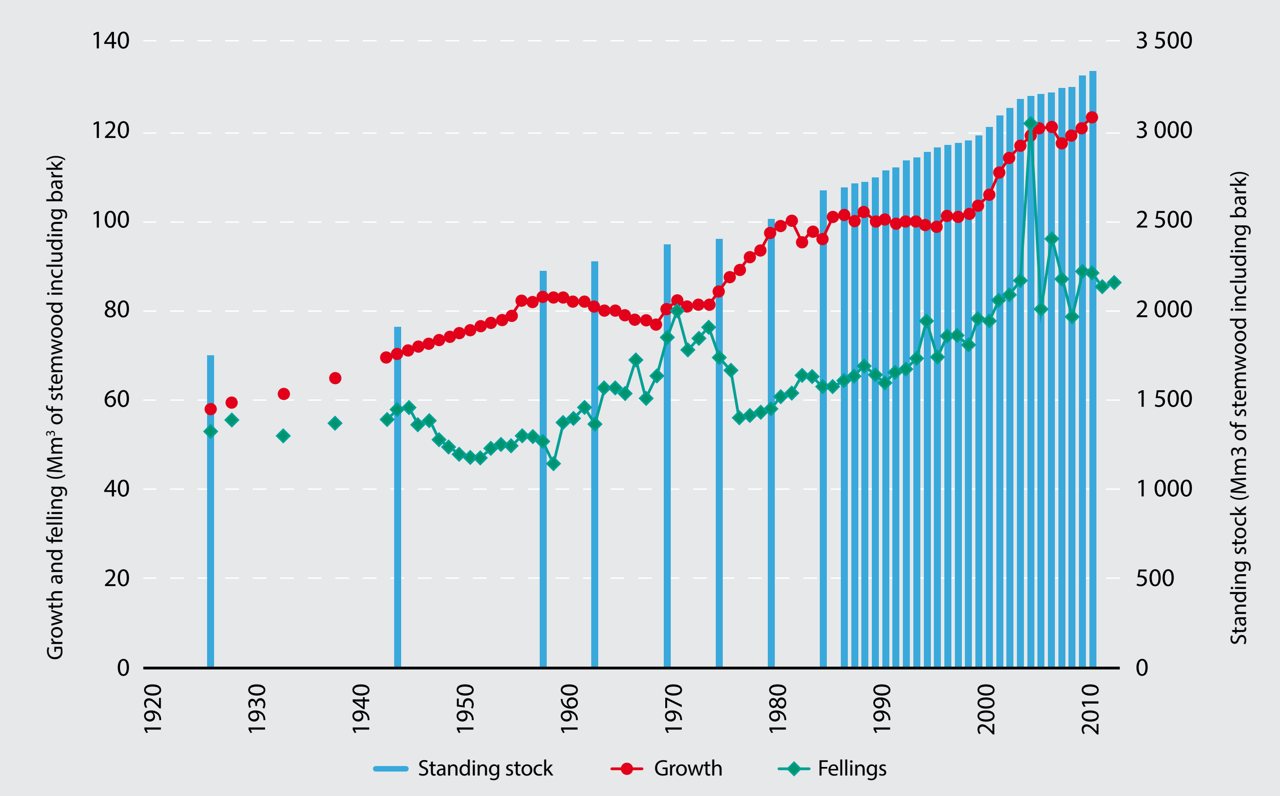
The residues that are left in the forest (tops, branches and stumps) are rapidly decomposed. 50 per cent of the biomass is gone after 15 years, and after a few more decades, almost everything is degraded. This means that all biogenic carbon returns to the atmosphere without replacing any fossil fuels. This carbon flow from decomposition of harvesting residues is around 47 million tonnes of carbon dioxide per year.

With regard to Börjesson's forecasts and other forecasts, the following should be noted:

» A basic assumption is that all good quality stemwood will, also in the future, be used for traditional production of sawn timber and pulp and paper. Increased harvest is also utilized for traditional industrial needs.

» The assessment made regarding ecological restrictions is very important for the amount of energy one can extract. There are great opportunities to develop technologies and compensatory measures that allow the extraction of higher proportions of tops, branches and stumps than assumed in Börjesson's cautious calculations. There are also positive syner-

» FIG. 7 STANDING STOCK, GROWTH AND FELLINGS IN SWEDISH FOREST FROM 1925 (million forest cubic meters)



The graph shows the development of standing stock (blue bars), annual growth (red) and fellings (green) from the 1920s to the present. The standing biomass stock and growth have doubled since the 1920s and harvesting has doubled since the 1950s.
Source: Swedish National Forest Inventory (Riksskogstaxeringen)

gies between nature conservation and harvesting of biomass for energy purposes, for example from harvesting in areas of nature preservation that often is beneficial to biodiversity.

For further discussion on uncertainty and possibilities to increase the potential, see page 20 (factors affecting future bioenergy potential).

TABLE 3, **INCREASED POTENTIAL OF FOREST-BASED BIOENERGY**

FUEL CATEGORY:	ENERGY (TWh)
DISCARDED, LOW VALUE WOOD ETC.	10
TOPS AND BRANCHES FROM FELLINGS	35
STUMPS	12
WOOD FROM CLEARING OPERATIONS	3
TOPS AND BRANCHES WITH INCREASED FERTILIZATION	4
RESIDUES FROM FOREST INDUSTRY*	10
TOTAL	74

**The volume of by-products increases due to increased harvesting of industrial wood.*

The table shows the upper long-term potential (2050) as stated by Pål Börjesson.

3.2 BIOENERGY FROM AGRICULTURE

Also for agriculture, we have based our estimates on Pål Börjesson's analysis (2016)[9]. The total yearly production of biomass on agricultural land is 74 TWh, of which 53 TWh will be removed as harvest products. A relatively small amount is currently used as energy, mainly grains for ethanol production, rapeseed for biodiesel (RME), straw and short rotation coppice (SRC) for heating, a total of 2.5 - 3 TWh.

According to Börjesson, the potential for increased biomass production on arable land for energy use is 18 - 20 TWh in the near future (uncertainty up to 22 TWh) and 35 - 40 TWh in the longer term (uncertainty up to 54 TWh). The potential includes better recovery of residues, mainly straw for combustion and manure for biogas production, and partly the cultivation of energy crops on land that is not currently cultivated or extensively cultivated. Above all, there are large areas of grassland that are not used for efficient cultivation. On good arable land, one can grow more grain and oil

9. Pål Börjesson, Potential för ökad tillförsel och avsättning av inhemsk biomassa i en växande svensk bioekonomi, Lunds Universitet 2016.

crops for biofuel production which also will produce protein feed. Increased plantations of SRC (salix) is also possible. On poorer land, fast-growing trees such as poplar and hybrid aspen can be planted, which, however, do not give full production of biomass in the short term.

As positive added effects of the cultivation, one obtains domestic production of protein feed that can replace imported soybean feed as well as an increased storage of carbon in agricultural soils.

These potentials have also been confirmed by Serina Ahlgren[10] in an IVA report on how agriculture can meet its climate targets[11].

Also here, we believe it is possible to reach Börjesson's higher values in the uncertainty ranges, giving 22 TWh in the short term and 54 TWh in the longer term. There is uncertainty here, mainly concerning how competitive Swedish food production will be, thus demanding more land for food production, and also regarding how large parts of the land will be used for domestic food consumption and for export.

TABLE 4, **INCREASED POTENTIAL OF AGRICULTURAL-BASED BIOENERGY**

FUEL CATEGORY:	ENERGY (TWh)
STRAW, CROP RESIDUES	4
ENERGY CROPS ON SURPLUS LAND	30
ENERGY CROPS ON POORLY UTILIZED GRASSLAND	10
FAST GROWING TREES ON ABANDONED FIELDS	4
BIOGAS FROM MANURE, WASTE, RESIDUES	6
TOTAL	54

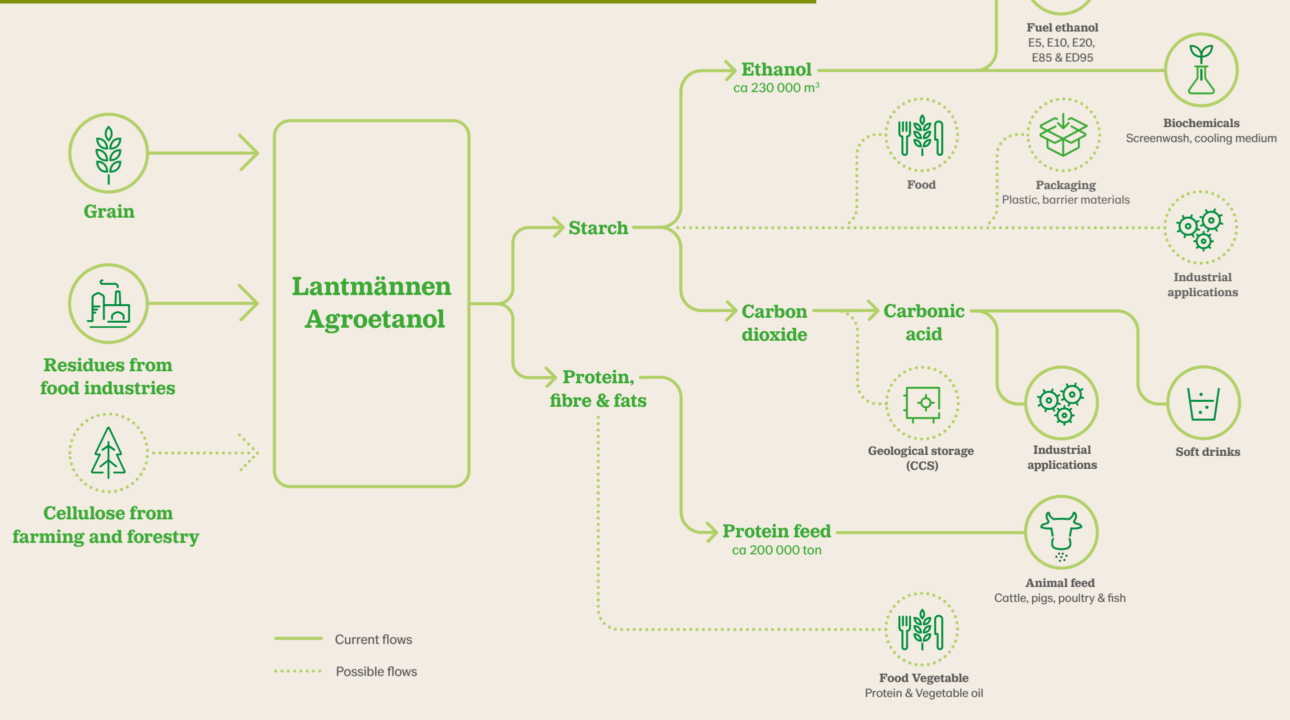
The table shows the upper long-term potential (2050) as stated by Pål Börjesson.

10. Serina Ahlgren m fl, Biodrivmedel och markanvändning i Sverige, Miljö- och energisystem, Lunds Universitet 2017.
11. IVA 2019, Så klarar det svenska jordbruket klimatmålen, delrapport från IVA-projektet Vägval för klimatet.

Photo: Stig Larsson

Swedish researchers and companies have developed cultivation systems for fast-growing woody plants such as willow and poplar, which can be planted on arable land and give high harvests of biomass. The picture shows a salix cultivation.

» FIG. 8 **BIOREFINERY LANTMÄNNEN AGROETANOL IN NORRKÖPING**



Lantmännen Agroetanol is an example of a highly efficient biorefinery. The solid lines show today's production. Dashed lines show possible future development. Biomass based electricity and steam from E.on Händelöverket are used as the energy source for the processes. The produced ethanol has a greenhouse gas reduction of 95 per cent compared to the gasoline being replaced.

Source: Lantmännen, "Farming of the Future – the road to climate neutral farming 2050", Stockholm 2019.

Straw is used to a small extent as fuel in Sweden. In Denmark, on the other hand, there are many heat and power plants that use straw as their energy source. Straw could also be a raw material for the production of biofuels for transport.

3.3 BIOENERGY FROM WASTE

The population is growing rapidly in Sweden, and the consumption of goods is increasing with a rising GDP. However, in recent times there has been a "decoupling" between waste volumes and increased economic activity by an increasing proportion of the economy relating to services. A report from the National Institute of Economic Research in 2016[12] calculated that a GDP growth of 64 per cent in 2014 - 2035 would increase waste volumes by 33 per cent. Great efforts are also being made to increase material recycling and to create a circular economy. In 2017, SMED (Svenska MiljöEmissionsData) estimates that the amount of combustible waste will increase from about 6 million tonnes today to about 8 million tonnes in 2035[13]. With an energy content of 3 MWh per tonne, this would correspond to 6 TWh increased energy recovery from waste.

A considerable part of the waste consists of materials of fossil origin - today about 40 per cent of the energy content. It is mainly plastics, but also fossil-based textiles, paint and other materials. The proportion of fossil waste will decrease as an increased proportion of plastics and textiles will be bio-based.

Due to incentives for a more circular economy, material recycling is likely to increase, but there will be large volumes of residual waste that cannot or should not be recycled. We assume that a significant portion of the energy supply for district heating will be waste for the foreseeable future. We reject the alternative of refraining from burning waste of fossil origin; Landfill can never be seen as a long-term sustainable alternative.

Basically, all biogenic products from forestry and agriculture that are not consumed as food or animal feed or that do not "disappear" through landfill, littering, through the influence of microorganisms or fire, can be recycled as energy. In Sweden, this is already largely done through landfill bans, well-organized recycling, waste incineration and utilization of sludge for biogas production. However, a high proportion of Swedish bio-based products (wood products, paper, food) end up abroad through export, where a large proportion still ends up in landfills, where recycling is not as well organized, and where energy is lost and the carbon content is released as carbon dioxide or methane upon decomposition.

12. Konjunkturinstitutet, Miljö, ekonomi och politik 2016, miljöekonomisk rapport.
13. SMED/IVL 2017, Framtida avfallsmängder och avfallsbehandlingskapacitet, SMED Rapport 2017:1.

Photo: Borlänge Energi

A large number of Swedish cogeneration plants and heat plants use waste as fuel. About 60 per cent of household waste is biological material.

3.3.1 Biogas potential

By 2023, all municipalities in Sweden must offer collection of compostable household waste, mainly waste from kitchens. Together with waste from restaurants, grocery stores, the food industry, manure, sludge from wastewater treatment plants and some other industrial waste streams this will become raw material for the production of biogas. This potential is included in Pål Börjesson's calculations of the agricultural potential[14], but can also be seen as a part of the potential from waste. Börjesson estimates the potential for biogas production through anaerobic digestion to 4 - 5 TWh, which is just about a doubling from today, with an uncertainty interval of up to 6 TWh. The target set in “Biogasmarknadsutredningen” (the Swedish biogas study 2019) is 10 TWh of biogas production in 2030, of which 7 TWh would be produced by anaerobic digestion[15].

Reduced food chain wastage and reduced livestock farming reduce the potential while increased population provides increased potential.

Redistributing waste from energy extraction through combustion to biogas production does not produce more energy and climate benefits, as the efficiency of biogas production is lower than in the production of electricity and heat in efficient cogeneration plants.

The advantage of biogas is mainly the recovery of nutrients.

14. Pål Börjesson, Potential för ökad tillförsel och avsättning av inhemsk biomassa i en växande svensk bioekonomi, Lunds Universitet 2016.
15. Mer biogas, betänkande av Biogasmarknadsutredningen, SOU 2019:63.

3.4 BIOENERGY FROM PEAT

The use of peat for energy production is currently around 1 TWh and has decreased mainly due to peat burning being covered by the EU Emissions Trading (EU ETS).

The report "Sustainable use of peat, SOU 2002:100" (Uthållig användning av torv, SOU 2002:100) defines peat as a "slowly renewable biomass fuel". In addition to energy production, peat is harvested primarily for cultivation purposes and for usage within in livestock farming.

Peatland growth was estimated to 6 - 17 TWh per year in the report mentioned[16]. There is a great uncertainty regarding the amount of carbon up-take through the growth of peat. An energy production at the same level as the up-take could be regarded as climate neutral at the national level.

Previously drained peat areas leak large volumes of carbon dioxide through continuous decomposition. Ditched and drained peat lands exist both as organic soils on farmland, as drained forest land with productive forestry, and as drained bogs. On these lands one could harvest peat and later restore these areas to become carbon sinks, either as new forest or as wetlands. Directing peat harvest to the most optimal areas, through a system of "climate-adapted peat harvest" may give climate benefits in the middle term[17].

Co-firing with peat gives cleaner combustion and higher efficiencies[18]. A future application of CCS technology means that peat that is co-fired with biofuels can then be regarded as a climate-neutral fuel.

Peat is valuable as a back-up fuel since it is easy to store. When, in 2018, there was a long period of cold weather and a following shortage of fuels in a number of heat plants, the use of energy peat increased considerably.

3.5 AQUATIC ENERGY

Aquatic energy involves the cultivation of algae or other plants in water. Pål Börjesson has estimated that the potential in Sweden is relatively small, and indicates as a realistic level of 0.6 - 1.5 TWh in 2050.

3.6 MARGINAL BIOMASS RESOURCES

Alongside biomass from regular forestry and agriculture, there are significant added potentials of "marginal biomass". The Department of Ecology at the Swedish University of Agricultural Sciences, SLU, has analyzed some of those marginal biomass assets[19]. A great part of this biomass can be found in connection with urban areas and infrastructure. Here are some examples that have been mapped:

- biomass in urban areas
- bush wood along roads, railways, etc.
- bush wood along arable land, ditches etc.
- bush wood under power lines
- biomass from nature preservation activities

The total urban area in Sweden is as large as the counties of Västmanland and Södermanland together (about 1.3 million hectares), or the equivalent of half the Swedish arable land.

SLU's conclusion is that there is an annual supply of biomass of 5 - 10 TWh from these marginal sources.

Photo: Kjell Andersson

Clearings along fields, forest edges and in nature conservation areas can give large amounts of biomass that can be used as fuel.

16. Uthållig användning av torv, SOU 2002:100.
17. Klimatpåverkan från torvproduktion ur ett systemperspektiv, Profu 2018.
18. Torv som samledningsbränsle, Luleå Tekniska universitet 2018.
19. SLU, Centrum för biologisk mångfald: Sly – en outnyttjad resurs.

TABLE 5, **SUMMARY OF POTENTIALS FOR INCREASED SUPPLY OF BIOENERGY**

ORIGIN:	CURRENT BIOENERGY USE, DOMESTIC (TWh)	CURRENT BIOENERGY USE, IMPORT (TWh)	POTENTIAL INCREASE, IN NEAR FUTURE (TWh)	POTENTIAL INCREASE, LONG-TERM (TWh)
FOREST	102	2*	42	74
AGRICULTURE	2	10**	22	54
AQUATIC	0	0	0	1
PEAT	1	0	5	5
WASTE	13	18***	6	6
MARGINAL BIOMASS	-	-	7	7
TOTAL	118	30	82	147

** The import of forest fuels mainly consists of a net import of pellets and a limited import of woodchips, primarily from the Baltics.*

*** The import primarily of biofuels or raw matarial for biofuels and bio-oil.*

**** The import of waste consists of municiapl waste and recycled wood for heat and power production and waste-based HVO and bio-oil. Note that some of this waste is fossil.*

The table shows today's bioenergy use and the long-term potential. Note that agriculture can become a very large supplier of energy in the future. Areas not longer needed for food production should be used for energy crops for biomass and biofuels.

3.7 DOMESTIC SUPPLY POTENTIAL – SUMMARY ASSESSMENT AND DISCUSSION

Svebio estimates that the overall potential for increased supply of domestic biomass for energy will be up to 82 TWh in the short term and up to 147 TWh in the longer term (in 25 to 30 years). The potential is great both from the forest and from arable land. Compared to the additional needs of 98 - 120 TWh, it can be noted that the potential is at a comparable level. This potential assessment is mainly based on static assessments and with relatively strong restrictions on ecological considerations. With greater focus on developing cultivation and harvesting systems as well as technology to reduce the negative effects of harvest, the potential can probably be increased. The low prices on biomass for energy purposes have held back such technology development so far. There are also a number of uncertainty factors, several of which indicate that there may be greater potentials than calculated here (see page 20).

If the biomass potential is to include a value for peat depends on the incentives, the view on climate-adapted peat use and the development of the CCS technology.

How quickly the potential needs to be utilized depends on how quickly the demand will increase, which depends on the development of incentives and technologies, as well as on the development of trade.

From a historical perspective, the Swedish utilization of bioenergy has increased by 3 - 4 TWh per year over a long period of time. From 1990 to 2017, the use of bioenergy increased by 82 TWh, from 61 TWh to 143 TWh, or by 3 TWh per year. From 2000 to 2017, growth in bioenergy was 3.5 TWh per year.

With a similar increase until 2030, the total bioenergy use will be 180 - 190 TWh. A growth of 4 TWh per year for bioenergy gives a use of 192 TWh in 2030, 232 TWh in 2040 and 252 TWh in 2045.

The suppliers of bioenergy have managed such growth over the past thirty years and will continue to do so. A smooth and steady growth means avoiding bottlenecks and rapid price fluctuations.

Svebio's assessment of increased supply of bioenergy is in good agreement with the assessment of increased use made by four Swedish authorities (the Swedish Energy Agency, the Swedish Environmental Protection Agency, the Swedish Forest Agency and the Swedish Agricultural Agency) in the report "Bioenergi på rätt sätt" (Bioenergy in the right way).[20]

The report assumes a use of around 130 TWh today, which corresponds to the use in 2015, excluding the fossil part of waste resources. It is stated that bioenergy use in the short term can increase to 170 - 180 TWh, and to 220 - 230 TWh by 2050. These numbers are lower than Svebio's assessment, but the report also shows that there is a broad consensus with the Swedish authorities that the supply of domestic sustainable bioenergy can increase considerably, by up to 100 TWh. The authorities' assessment is also very similar to our estimated increase in usage of around 100 TWh.

20. Bioenergi på rätt sätt – om hållbar bioenergi i Sverige och andra länder, en översikt initierad av Miljömålsrådet (Rapport 10, Skogsstyrelsen 2017).

3.7.1 Processing and primary energy requirements

The amount of primary energy in the form of biomass that will be required for different needs and purposes is determined partly by the extent to which refined fuels will be required and partly by the conversion efficiency of the production from biomass to finished product.

In some cases, there is only need for low-quality unprocessed biomass, where the price per MWh is the only important factor. This applies, for example, in the furnaces of the cement industry or in the baseload production of heating and cogeneration plants. The demand for unprocessed wood fuels can also increase to compensate for the extraction of raw material for processed fuels, for example when extracting lignin from black liquor at pulp mills.

For the requirements in the transport sector, biodiesel, bio-alcohols, bio-gasoline and bio-aviation fuel, high energy quality is necessary, and there will be energy losses when converting biomass to these fuels. Some of these losses can be recovered for district heating, drying or other low temperature requirements.

3.8 NEW TYPES OF BIOMASS BASED FUELS

Bioenergy includes a number of different raw materials, conversion techniques, fuels, and areas of use. There is a constant development, which can be difficult to grasp. Here are some areas where we see a rapid development today:

3.8.1 Biochar - torrefied fuels and charcoal

Charcoal has been used for a very long time, and is also today a significant fuel with extensive production and trade in developing countries, not least in Africa. Today, there is a new interest in charcoal, or as one sometimes prefers to say: "Biochar".

Charcoal is produced by heating the wood without access of oxygen, obtaining a cleaner carbon fuel from which, in addition to water, various volatile substances have been discharged.

The process can be driven variously far. With torrefaction, the biomass is heated at 250 - 300 degrees, which gives a "roasted fuel" that has a higher energy density than the original fuel. This reduces transport costs and offers advantages for different applications, for example combustion in existing coal boilers. The torrefied material is also water repellent which is a great advantage when storing the product.

In Sweden, this technology has been developed at Umeå University and by the company Bioendev.

The term biochar is often used for charcoal that is used as soil enhancement or for creating long-term carbon sinks. Today, there are several projects for the production of biochar.

Large-scale use of biochar is possible in the iron and steel industry. The company SSAB has tested the incorporation of biochar in its blast furnace in Brahestad, Finland, with good results.

We are likely to see both technical and commercial development of charcoal, biochar and torrefied biofuels in the coming years.

3.8.2 Biomethane and biopropane

Today, all biogas is produced by anaerobic digestion / fermentation by microorganisms at low temperatures in thermophilic and mesophilic processes from “easy-to-digest” raw materials such as food waste and manure. The biogas is either used as a raw gas with a relatively high proportion of carbon dioxide, or upgraded to pure methane gas.

Methane gas, biomethane, can also be produced by high temperature thermal gasification. This extends the raw material base to cellulosic raw materials and waste streams. The GoBiGas project in Gothenburg has shown that the technology is fully developed, but upscaling to larger plants is now required to reduce the cost.

In addition to the use of fossil natural gas (fossil methane), large volumes of liquefied petroleum gas (propane), produced from oil, are used in Swedish industries. Also, for these needs, there is a possibility to make bio-based alternatives. Bio-propane is produced in refineries when refining bio-oils to commercial fuels.

The gases can be used both in gaseous form, for example by injecting biomethane into an existing gas network, or in compressed form such as LBG (liquefied biogas), a replacement for LNG (liquefied natural gas).

3.8.3 Advanced biofuels

At EU level, advanced biofuels are defined as fuels made from certain raw materials, which cannot be used as food or feed. These raw materials are listed in an annex to the Renewables Directive, Annex IX, which is divided into two lists, where list B includes vegetable and animal fats and oils (used cooking oil), and list A covers other waste products and cellulose-containing raw materials.

The term "first generation biofuels" is sometimes used (e.g. ethanol from sugar cane, sugar beet, corn and other grains, as well as biodiesel from e.g. rapeseed), and also "second generation biofuels".

The Nordic countries have good conditions for producing advanced, second-generation biofuels, for example from raw materials from the forest. Extensive research and development work have been carried out for a long time. Investments are also made in demonstration plants and in commercial plants today.

The Swedish magazine "Bioenergi", no. 5/2019, listed no less than 65 projects for liquid biofuels in the Nordic countries, of which a large part concerns advanced biofuels. In addition, there are around 70 plants in Sweden where biogas is produced for transport purposes.

The expansion is now favoured by the introduction of an emissions reduction quota for road transport fuels, which rewards fuels with particularly high climate benefits. A similar quota system is planned for the aviation sector. In the Norwegian quota system for aviation, the fuel must come from raw materials listed in Annex IX.

A prerequisite for the quota systems to lead to investments in the production of advanced biofuels is that the quotas should be raised relatively quickly so that there will be an increased demand for large volumes. Increased volumes lead to lower production costs per liter of fuel produced. In addition to the emissions reduction quota, additional incentives are likely to be required to achieve sufficiently rapid expansion of production capacity, such as procurement with a system for "contract for difference".

3.8.4 Raw materials and semi-finished products for biofuels – bio-crude

The plans for the production of advanced biofuels include a wide variety of technologies, such as gasification, pyrolysis, hydrolysis and catalytic processes. The raw material can come from the forest and forest industry, such as tall oil and lignin from pulp mills, sawdust and bark from sawmills, logging residues, etc., or from agriculture, such as straw and energy crops. It can also be waste of various kinds, both bio-based or mixed, for example with plastic content.

Through various conversion techniques, it is possible to produce a semi-manufactured product, bio-crude, which can be further processed in the existing refineries, which today mainly use crude oil as raw material. Alternatively, a fuel is manufactured directly for the market. When choosing a method for production, it is important to meet the standards that exist for different fuels. This applies, for example, to biojet fuel.

One possible alternative use for bio-crude is to refrain from upgrading to vehicle fuel and instead produce a bio-oil that replaces heating oil in heating plants and other combustion processes.

The new types of biofuels being developed are very similar to their fossil counterparts. This facilitates the conversion from fossil fuels to renewable fuels by utilizing existing infrastructure and vehicles.

At the same time, development of clean biofuels and vehicles, dedicated for example for ethanol, methanol, DME and biogas, is taking place. Several different alternatives are needed to replace all fossil fuels.

Photo: Preem

Today, the refineries in Lysekil and Gothenburg make major investments to be able to produce larger volumes of biofuels for transport, including biojet fuel, and use more domestic raw material.

3.9 FACTORS AFFECTING FUTURE BIOENERGY POTENTIALS

It is impossible to specify a fixed future potential for biomass for energy purposes in Sweden or globally, as there are a number of uncertainties and dynamic effects. In short: "it depends". Here are some important aspects that affect the ability to mobilize biomass resources:

3.9.1 Generally increased productivity in forestry

Forest growth per hectare has increased by about one per cent per year in Sweden since the Second World War. The increase is due to a number of interacting factors that can be summarized under the concept of "better forest management". It is about better genetic material, about replacing sparse stands with denser stands, about measures against pests, about better planning, about increased knowledge and skills, about research, about better machinery and less land damage, etc. It is likely that this trend will continue, but there is no consensus on how strong the effect will be in the future.

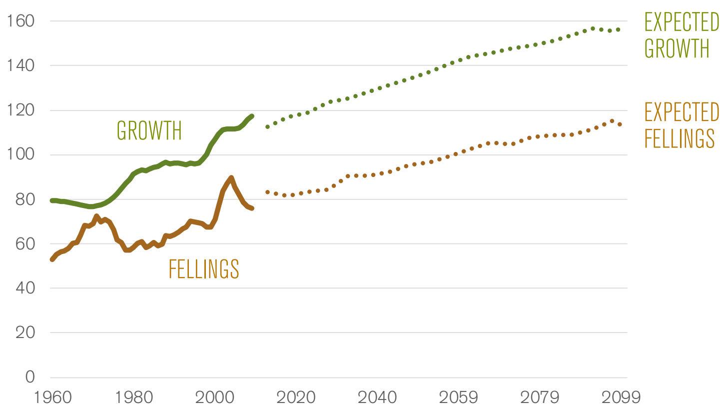
3.9.2 Development of cultivation systems for fast growing tree species and energy crops

Sweden has developed a system for cultivation of Salix, in Sweden often called energy forest cultivation, internationally called SRC (Short Rotation Coppice, cultivation of shoots in short rotations). Similar cultivation systems exist for other fast-growing tree species, such as Poplar and Hybrid aspen. Common to cultivation of these woody energy crops is that they are planted on arable land and harvested at shorter intervals than forest trees. The yield in tonnes of biomass per hectare can be very high. Systems for cultivation of energy crops can be developed and give increased potential in the future. Breeding of forest trees also offers increased potential.

3.9.3 Increased harvests and possible fertilization in forestry

In agriculture there is a similar rate of increase in yield. In addition to the yield for individual crops, there may be an increase in the total yield, and thus the absorption of carbon dioxide, through developed cultivation systems, for example with increased cultivation of intermediary crops or with better plant sequences. An example is the cultivation of rapeseed and grassy plants in plant sequences with mainly cereal crops. The company Lantmännen expects an increase in yield in Swedish wheat cultivation by 38 per cent between 2015 and 2030, and

» FIG. 9 **EXPECTED INCREASED GROWTH ENABLES INCREASED FELLINGS (million cubic meters)**



Expected increased growth according to the Swedish National Forest Inventory (Riksskogstaxeringen) and expected increased fellings.
Source: "Temaavsnitt: Skogen då, nu och i framtiden, Skogsdata 2016", Swedish University of Agrucultural Sciences (SLU)

an additional 10 per cent until 2050. Increased yields result in increased volumes of by-products and can free up land for increased cultivation of energy crops.

Fertilization is applied to a relatively small extent in Swedish forestry. In some soil types, fertilization can result in increased biomass production. Dedicating a certain portion of the Swedish forest land for intensive cultivation for high biomass production can be of great importance in the long term.

3.9.4 The balance between environmental objectives

A high mobilization of biomass provides great climate benefit through the substitution of fossil fuels and materials. At the same time, there is concern that a high level of mobilization goes beyond the limit for long-term sustainable production and is detrimental to biodiversity and other environmental targets. Simply put, one can say that there must be a balance between different environmental objectives. In policy, it is about how much land should be set aside for different types of nature protection and how much the production of forest raw material therefore would be reduced and thus also biomass for energy purposes. Also, the question of how much of the tops and branches can be taken out for environmental reasons and the question of stump harvest is about balancing different environmental objectives.

At best, several environmental objectives can be strengthened through properly designed actions. There may also be positive synergies between nature conservation and bioenergy. Areas devoted to nature conservation and consideration for biodiversity often need to be taken care of to maintain their natural values. There are estimates that 40 per cent of these areas require some type of maintenance measures, such as clearings that lead to biomass being collected. From a national perspective, these areas can provide significant volumes of energy.

3.9.5 The share of forest growth harvested

This aspect is largely linked to the previous question, but also has other components. According to the Swedish National Forest Assessment (Riksskogstaxeringen), harvesting has been around 70 - 75 per cent of the total growth in productive forest land over the past decades. To a certain extent, the relatively low level is due to various provisions for nature conservation and other considerations. But it also depends on other structural factors. The Swedish forest is owned by about 300,000 forest owners, most with relatively small forest holdings. Most forest owners have the forest as a secondary income. Taxation rules and other factors may result in that many refrain from an optimal harvest. An increased level of harvesting in relation to growth would have a major impact on the supply of wood and thus the supply of by-products and harvest residues.

3.9.6 Possible positive synergies

Increased clearing and thinning can result in both increased production, higher quality of wood and increased volumes of biofuel, provided that there are technical solutions for harvesting at a reasonable cost. The view on extraction of clearing wood for energy purposes differs somewhat between Sweden and Finland. In Finland, clearing measures have been subsidized for individual forest users.

3.9.7 The use of the harvested biomass

Most potential calculations are based on an assumption that the wood is being used as today, with about half of the stemwood being sawed and half being pulp wood, while the by-products become energy. Harvesting residues are also collected. One cannot assume that this allocation of the biomass will be exactly the same in a developed bioeconomy. The trade-off between construction materials, paper production, energy production and production of new products and materials can be different than today, which can affect the supply of biomass for energy purposes in both a positive and a negative direction.

3.9.8 The effect of a warmer climate

A warmer global climate has a greater impact over the continents than over the oceans, with twice as much increase in average temperature, and greater temperature increase at higher latitudes, nearer the poles, than at lower latitudes. Climate change in Northern Europe can thus be very big. At the same time, there is a risk that disruptions in the strength of the Gulf Stream can create a cooler climate. The latter is more uncertain. Several effects are more likely, in addition to higher average temperatures: extended vegetation period, increased rainfall and expansion of forest land in northern Sweden. Together with the increased carbon dioxide content in the air, all these factors lead to higher growth in the forests.

Some negative effects are also possible, such as increased infestation of insects and other pests and increased frequency of forest fires.

All in all, the effect of climate change is likely to greatly increase forest growth in Sweden.

3.9.9 Effects of technology development

Although technology development does not increase the volume of primary biofuel, advanced technology can reduce losses and increase final yield and thus the end use of bioenergy. This can include increased efficiency, less waste, more efficient handling and logistics systems and much more. Technological development also leads to cost reductions that increase the economically available potential. Most potential calculations are made with significant reductions from technical and ecological potential to "economic potential". The latter can be affected by technology development.

3.9.10 Dynamic market effects

Analysis of potentials for production and of future needs are usually based on static calculations based on existing technology, existing cultivation systems and sometimes expected technological development.

It is especially difficult to assess dynamic effects on the market. Increased demand for biofuels leads to increased supply that stimulates market players to mobilize raw material resources and develop technology and logistics. Experience from the Swedish market is that increased demand in the short term can lead to increased prices, but that in the longer term it gives falling prices and costs together with increased volumes. Most potential calculations are likely to underestimate the fuel volumes that may be available in a dynamic market.


Photo: Stockarydsterminalen

Expansion of terminals, rail and boat transport facilitates fuel supply at long distances.

3.9.11 Improved logistics

Biofuels have long been seen as a local fuel. But in recent years, the trade in fuels has developed strongly with the expansion of terminals, rail and sea transport. Longer and heavier trucks affect transport costs very strongly. The effect of improved logistics will be reduced economic constraints of the potential .

3.9.12 Utilization of marginal resources

A growing market and higher prices lead to an increased supply. The potential calculations that have been made have mostly been based on the existing forest and agricultural systems and their land assets. Alongside the agricultural and forestry land, there are significant areas of marginal land that are relatively poorly mapped. This applies, for example, to the urban area.

Most or all of these factors can significantly increase the potential of biomass for energy purposes.

4. SUSTAINABLE BIOENERGY

The question of what is sustainable bioenergy and what can be produced in a sustainable way is discussed both in Sweden, within the EU, and globally. Analysis of what is possible production and extraction of biogenic natural resources are mapped by research and by experience as the supply systems develop. Legislation sets out terms and conditions. Standards and voluntary certification systems are used by market actors to demonstrate that sustainability conditions are met.

At EU level, with the recently adopted and updated Renewable Energy Directive (REDII recast), there is a comprehensive system of sustainability criteria for both solid, liquid and gaseous biofuels for all uses - transport, electricity and heat.

Sustainability criteria have been in place for biofuels for transport and other liquid biofuels since 2009. The criteria stipulate, for example, that the raw material must not come from land that has been deforested or from peatlands ditched after 2008, or from nature-protected areas. The use must also achieve a certain minimum greenhouse gas reduction compared to fossil fuels. For waste-based fuels, less greenhouse gas reduction requirements are set. By a supplementary directive in 2015, clarifications were made to, among other things, favour biofuels from waste and cellulose, and also introduced restrictions on biofuels from agricultural crops.

Photo: Kjell Andersson

The new criteria for forest-based biomass are based on a system of risk assessment whereby, for countries, regions and supply areas, the fuel user must evaluate whether existing legislation and control systems can guarantee that the raw material is legally extracted, that nature conservation and biodiversity are respected, that regeneration takes place, that the long-term carbon balance is maintained, and the soil is not degraded. The risk assessment system has been chosen to avoid a new administrative control system in addition to existing forest management legislation in place in EU Member States. If the risk assessment shows that it is not possible to meet the criteria with existing systems, users of forest biomass may be required to have their biomass certified according to an EU approved certification system or otherwise show that the conditions are met.

The EU's sustainability criteria for biofuels for transport and liquid biofuels are applied through the Swedish Sustainability Act (Hållbarhetslagen). How the extended system of sustainability criteria for solid biofuels and for biogas for electricity and heat will be applied in Sweden is being investigated by the government and the relevant authorities.

The sustainability criteria for solid biofuels will apply to plants with an installed thermal capacity exceeding 20 MW. Thus, smaller actors do not have to handle the additional bureaucracy around sustainability reporting. One of the reasons for this threshold is that forest biomass is supplied by millions of, often small, forest owners around Europe, and that there are several thousand small heat plants using biomass, often with a local fuel supply.

In addition to EU directives and Swedish legislation, there is an increasingly developed system for standardization and certification of fuels, both to guarantee the quality of the fuels and to ensure sustainability. Some of these systems go beyond the minimum requirements set by EU directives and legislation. The global ISO standardization organization has developed a standard for certification of sustainable biofuels (ISO 13065: 2015).

« Coarse dead wood must be left in the forest during felling.

4.1 SWEDISH RESEARCH ON SUSTAINABLE BIOFUELS

Extensive research has been conducted in Sweden to study the environmental effects of biomass extraction for energy from forests and fields, and to develop sustainable supply chains. In recent years, the research has been mainly funded by the Swedish Energy Agency, which summarizes the results of the research in synthesis reports.[21]

The research has dealt with issues such as effects on soil and nutrient content when extracting tops and branches in final felling and thinning, impact on biodiversity, leaching to watercourses, effects of soil damage on leaching of mercury, effects of ash recycling, carbon balance calculations, methane and nitrous oxide formation, etc.

During the years 2007 - 2015, a comprehensive research program on stump harvesting was carried out in the light of the criticism and concerns that existed regarding the harvesting of stumps. For example, stump harvest is not accepted by the FSC (Forest Stewardship Council, certification system for forest products).

Researchers from the "Theme stumps" and "Theme2 stumps" participated in research programs from the Swedish University of Agricultural Sciences (SLU), Uppsala, Umeå and Lund Universities, and Skogforsk (the central research body for the Swedish forestry sector). 42 researchers participated in the popular scientific final report "Stubbskörd – hur påverkas klimat och miljö?" (Stump Harvest – how is it affecting climate and environment?) from 2017.[22] Areas studied were how stump harvesting affects land/soil, plants, fungi, small animals, greenhouse gases, nitrogen leaching, mercury and forest production.

How great the climate benefit is of using stumps instead of fossil fuels, how biodiversity is affected by different harvest levels and whether creating more high stumps after harvest can compensate for biodiversity loss was also analyzed. During the second four-year period 2012 - 2015, 24 research projects were carried out with a budget of SEK 52.1 million. The Swedish Energy Agency contributed half the cost.

Stumps are a very large potential source of energy. As shown in the flow chart on page 10, the total energy content of stumps and roots from all final felling and thinning is 83 TWh per year. In various potential calculations over the years, it has been stated that the stumps could produce 20-30 TWh of energy. Pål Börjesson calculates in his main alternatives with relatively little harvest of stumps, in the short term 4 - 6 TWh and in the long term 5 - 7 TWh, but with uncertainty intervals up to 12 TWh in the long term.

What does the research say about extracting stumps for energy purposes? There is no exact answer to how much of the stumps could be harvested without negative environmental impact. When harvesting stumps on 30 per cent of the harvested area, it is estimated that there may be risks to some stationary and specialized species. The land effects are estimated to be relatively limited at that harvest level.

One conclusion that can be drawn from the ambitious research program is that there is no need to stop stump harvesting completely due to nature conservation reasons, but that there is still uncertainty about the proportion of stumps that can be harvested. Since the cost of stump harvesting is higher than that of harvesting of tops and branches, it will surely take several years before the issue of stump harvesting on a larger scale will be decided.

4.2 THE CONSOLIDATED CLIMATE BENEFIT OF THE FOREST BIOENERGY SYSTEM

The Swedish forest-bioenergy system has a significant overall climate benefit. It has been demonstrated in some new studies and reports. Svebio, in collaboration with IRENA, the International Renewable Energy Agency, shows the overall climate benefit in the report "Bioenergy from boreal forests - Swedish approach to sustainable wood use" (2019).[23] The company SCA has done its own analysis of the company's overall climate benefit[24], and Skogsindustrierna (Swedish Forest Industries Federation) published the report "How big is the contribution of the forest industry to climate action" in the summer of 2019.[25] For the latter two reports, Peter Holmgren, FutureVistas, has been responsible for the calculations. Analysis of the Swedish forest's overall climate benefit have also been carried out by Nordic Forest Research and by the Swedish University of Agricultural Sciences (Tomas Lundmark and others).[26] During 2019, Skogforsk also published a report on forestry's climate benefit, written by Rolf Björheden.[27]

21. Energimyndigheten, Miljöpåverkan av skogsbränsleuttag, en syntes av forskningsläget baserat på Bränsleprogrammet hållbarhet 2011 - 2016 (ER 2018:02).
22. Tryggve Persson m fl., Stubbskörd – hur påverkas klimat och miljö? SLU 2017.
23. IRENA, Kjell Andersson och Jeffrey Skeer, Bioenergy from boreal forests – Swedish approach to sustainable wood use.
24. Peter Holmgren och Katarina Kolar, Reporting the overall climate impact of a forestry corporation – the case of SCA.
25. Skogsindustrierna, rapport av Peter Holmgren, Så stort är skogsnäringens bidrag i klimatarbetet.
26. Tomas Lundmark m fl, Potential Roles of Swedish Forestry in the Context of Climate Change Mitigation (Forests 2014).
27. Skogforsk, Rolf Björheden, Det svenska skogsbrukets klimatpåverkan – upptag och utsläpp av växthusgasen koldioxid.

The forest-bioenergy system provides climate benefits in several stages:

» Gross carbon dioxide up-take from the atmosphere in growing forests.

» Net up-take of carbon dioxide causing an increased volume of forest biomass (carbon storage in forest and land).

» Substitution benefits through the use of wood and paper instead of other materials with high carbon footprint.

» Substitution benefits by replacing fossil fuels with biofuels.

In the future, further climate benefits can be added through bio-CCS, i.e. the capture and storage of biogenic carbon dioxide from industries and cogeneration plants that burn wood fuels.

The report from Skogsindustrierna gives a somewhat different picture than the IRENA report. On the one hand, no substitution benefit has been calculated from the internal use of bioenergy in the forest industry, and on the other, a much greater substitution benefit has been calculated on the use of wood products, and finally, a value for substitution benefit through paper use, corresponding to the combustion value, has been included. Greater net up-take in the forest has also been assumed. The report comes to a total yearly climate benefit of 93 Mt CO_2. Adding to the values of the IRENA report the values from Skogsindustrierna for substitution benefit from paper use, the total will be 94 Mt CO_2.

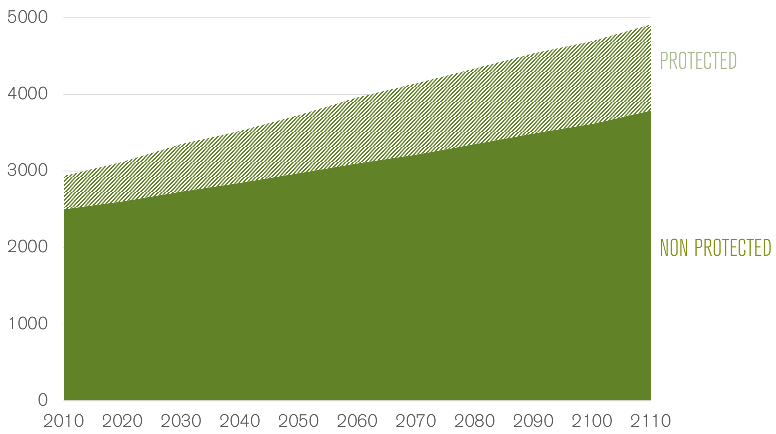
Continued analysis of the Swedish forest-bioenergy system's climate benefits are needed, but one conclusion is that it is probably around 90 Mt CO_2.

This can be compared with the Swedish national greenhouse gas emissions, which are about 52 million tonnes of CO_2 equivalents, of which carbon dioxide emissions account for about 42 million tonnes.

TABLE 6, **THE CLIMATE BENEFIT IN MILLIONS TONNES OF CO_2/YEAR**	
GROSS UPTAKE IN GROWING FOREST	150 MT CO_2
CLIMATE BENEFIT:	
NET UPTAKE - INCREASE OF STANDING STOCK	37 MT CO_2
SUBSTITUTION BENEFIT THROUGH USE OF WOOD PRODUCTS	12 MT CO_2
BENEFIT THROUGH SUBSTITUTION OF FOSSIL FUELS	33 MT CO_2
TOTAL YEARLY CLIMATE BENEFIT	82 MT CO_2

The climate benefit of the forest and forestry is very high. The table shows the values given in the report "Bioenergy from boreal forests - Swedish approach to sustainable wood use ", published by Svebio and IRENA.

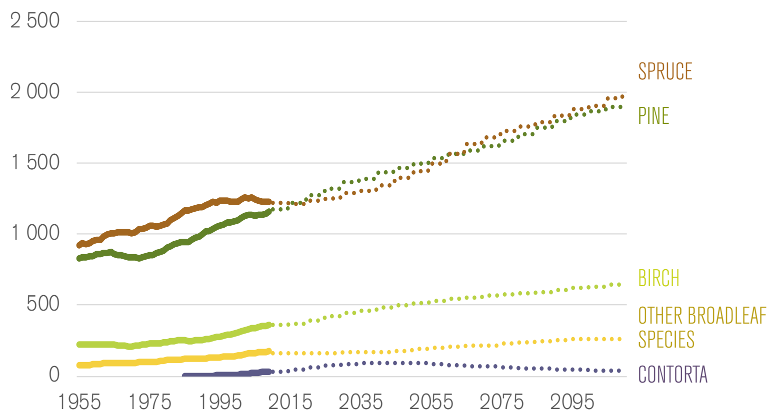
» FIG. 10 **CONTINUED INCREASE OF STANDING STOCK IN FOREST 2010 - 2110** (millions m³sk)



The standing stock on productive forest land has doubled from the 1920s to today, and is expected to increase by another 50 per cent by 2100.

Source: "Temaavsnitt: Skogen då, nu och i framtiden, Skogsdata 2016", Swedish University of Agrucultural Sciences (SLU)

» FIG. 11 **DEVELOPMENT OF STANDING STOCK FOR DIFFERENT FOREST SPECIES** (miljoner m³sk)



The standing stock will increase for all dominant tree species - pine, spruce and birch, as well as for other broadleaf species. Contorta is a fast-growing Canadian pine introduced in Sweden.

Source: "Temaavsnitt: Skogen då, nu och i framtiden, Skogsdata 2016", Swedish University of Agrucultural Sciences (SLU)

By applying bio-CCS to the 35 largest bioenergy combustion plants, in the pulp mills and the larger CHPs (combined heat and power plants), one could increase the climate benefit in the system by an additional 29 Mt CO_2 (see page 27) to about 120 Mt CO_2.

One way to further improve the forest's climate benefit is to increase the harvest of tops, branches and stumps and thus reduce the loss of 47 Mt CO_2 to the atmosphere that is currently taking place by decomposition of these residues that are not being utilized.

Already today, the Swedish forest-bioenergy system provides a climate benefit equivalent to 9 tonnes of carbon dioxide per Swede, and this could increase to 12 tonnes of carbon dioxide per person. However, part of this climate benefit occurs abroad when Sweden's exported forest products are used, recycled, and, as waste, used for energy purposes.

4.3 GREEN HOUSE GAS BALANCE – CARBON DEBT

It is increasingly claimed by various debaters that bioenergy is not climate neutral. Some claim that "biofuels are worse than coal". A common statement is that "for the atmosphere it makes no difference if the carbon dioxide originates from fossil fuels or biofuels - it has the same climate impact". A common argument is also that it is better to leave the forest standing to take up and store carbon dioxide than to use the forest as energy.

The reasoning is often based on the theory of carbon debt. It is claimed that it takes a long time to repay the carbon debt that you get when harvesting and combusting biomass from forests. Only after 60 - 100 years, a new tree has grown up and absorbed all the carbon dioxide lost during combustion.

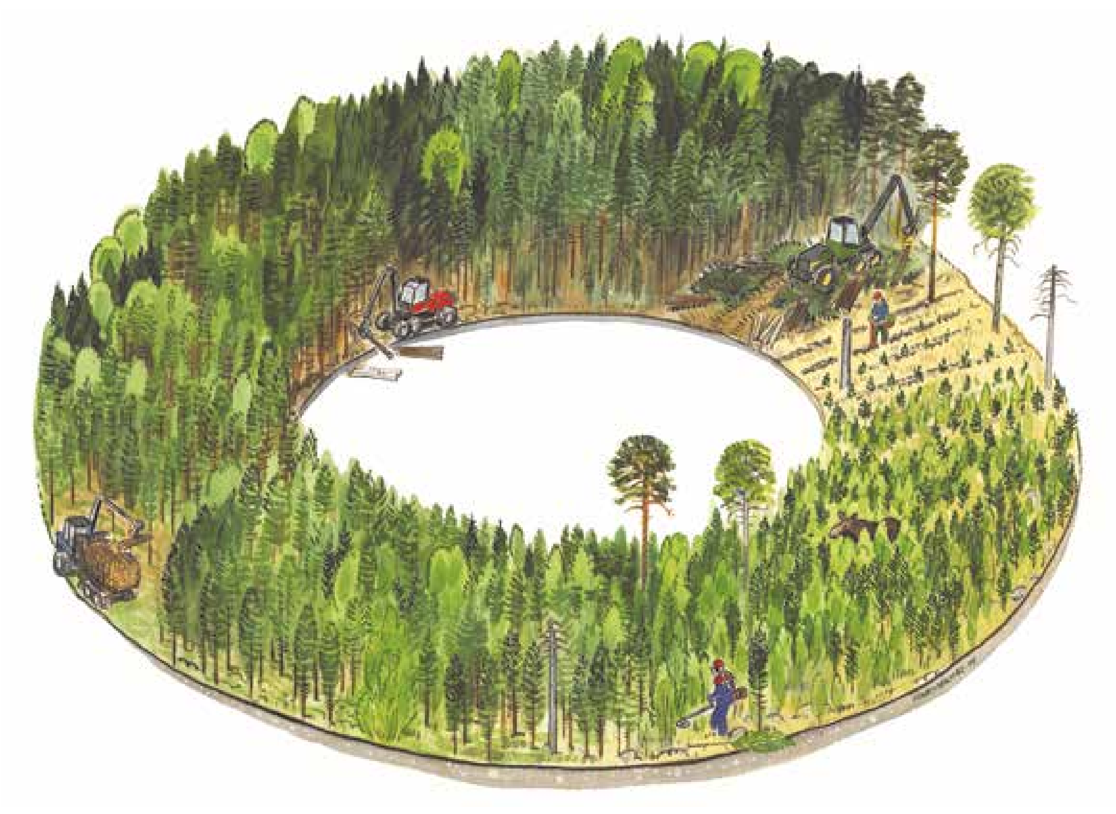
The theory of carbon debt may seem reasonable if you look only at a single forest stand and start measuring when harvesting. But choosing a particular time point in a stand and making all calculations and conclusions based on the state of that stand at that time is a too limited approach. In science, studies are usually done either on individuals or populations. If you do carbon studies on an individual tree, it is obvious that the tree must grow and collect carbon dioxide before you can burn it - the tree is carbon positive. Doing the calculations on the population is the same as looking at the entire landscape or all the forest in Sweden and then there is no carbon debt either.

As shown in the previous section, the Swedish forest has a higher up-take of carbon dioxide than the emissions that occur through the use and combustion of the harvested biomass. The amount of biomass in the forest is increasing year by year, and has done so for a hundred years, despite the fact that the harvest has constantly increased. Instead of carbon debt, we have increased assets of biomass in our forests.

By harvesting old forest, we are giving way to new and faster growing young forest, which absorbs more carbon dioxide than the old trees.

A forest landscape composed of trees of different ages, with a high proportion of young forest, has the highest average growth and thus also the largest absorption of carbon dioxide. Saving the forest and reduce harvesting can produce a short-term climate

» FIG. 12 **CARBON-NEUTRAL CYCLE OF WOOD GROWTH AND HARVEST**



A forest system with forests of all age is in balance and produces carbon-neutral products as the harvest corresponds to the total growth. The circle illustrates the managed forestry landscape. It consists of 100 age classes and one hundredth (one age class) is harvested every year. In all age classes, from planting to harvesting, there is growth corresponding to the harvested volume.

Illustration: Sveaskog

benefit, but gives a relatively lower absorption of carbon dioxide as the forest ages. Meanwhile, increased emissions have also been achieved through the use of fossil fuels that could otherwise have been replaced.

4.4 BIO-CCS

Bioenergy is the only energy source that can provide "negative emissions" with today's known technology at a reasonable cost and in sufficient volumes. By separating and storing biogenic carbon, carbon dioxide content in the atmosphere can be reduced. This process, bio-CCS or BECCS (bioenergy with carbon capture and storage), is highlighted by IPCC (the International Panel on Climate Change) in most of the scenarios that are able to meet the 1.5° target.

With a high proportion of bioenergy in the energy system, through combustion in large plants, Sweden has unique and good opportunities to become a pioneer in the application of bio-CCS. A summary in the Swedish magazine Bioenergi no 2/2019[28] shows that 23 plants in the forest industry (pulp mills) and the 15 largest biomass and waste combined heat and power plants emit a total of 32 million tonnes of carbon dioxide, of which approximately 3 million tonnes are of fossil origin, mainly from plastic in waste. The list includes plants emitting more than 300,000 tonnes of carbon dioxide per year.

If 29 million tonnes of biogenic carbon dioxide could be stored, this would correspond to more than half of the Swedish annual greenhouse gas emissions and 70 per cent of the Swedish carbon dioxide emissions. It would thus further increase the climate benefit of the Swedish forest-bioenergy system.

In addition to capturing carbon dioxide in fluegases from large combustion plants, carbon dioxide can be collected in concentrated form from ethanol and biogas plants. The carbon dioxide is produced by the microorganisms that drive the fermentation process. Such carbon dioxide is already recovered today at the company Lantmännen Agroetanol in Norrköping, Sweden, and is sold, among other things, to the food industry as "green carbon dioxide".

Industries other than pulp mills can also apply bio-CCS. This is the case, for example, for industries with large boilers that have been converted from fossil fuels to biomass fuels. One example is the cement industry, where already a significant portion of the fuel used is of biogenic origin.

28. "Stor potential för att fånga in och lagra bio-CO_2", artikel i Bioenergi 2/2019.

Photo: Stockholm Exergi

Värtaverket in Stockholm is Sweden's largest biomass-fired cogeneration plant, inaugurated in 2016. At this plant, bio-CCS could provide the separation of 800,000 tonnes of carbon dioxide for storage per year.

Application of CCS could also justify some use of peat, which has advantages as fuel at combustion.

In Sweden, pilot projects and analysis of CCS and bio-CCS are being carried out at Preem oil refinery and Stockholm Exergi, the district heating company in the capital, among other companies. Stockholm Exergi uses potassium carbonate to capture the carbon dioxide. The company's calculations show a total cost of 60 to 93 euros per tonne of carbon dioxide for large-scale application at Värtaverket in Stockholm, Sweden's largest biomass boiler in district heating.[29]The cost includes capture from the fluegas, transport and storage in the Norwegian North Sea. In terms of energy, the method would give a 37 per cent lower electricity output but 9 per cent higher heat output at the combined heat and power plant, a total energy loss of only 2 per cent.

An alternative to CCS is CCU (Carbon Capture and Utilization), which means that the captured carbon dioxide is used as raw material for new fuels or to replace carbon dioxide from fossil raw material, as is done by Lantmännen Agroetanol mentioned earlier. With the help of hydrogen, new hydrocarbon fuels are created that can replace fossil fuels. In the future, hydrogen can be produced using renewable electricity, for example from solar or wind power. In this case, the biogenic coal is used "for a second round" and the fossil carbon that is replaced will basically remain in the bedrock. If the CCU fuel is a vehicle fuel, there is no way to capture it again.

29. Fabian Levihn m fl, Introducing BECCS through HPC to the research agenda: The case of combined heat and power in Stockholm (Energy Reports 5, 2019).

4.5 FOSSIL-FREE BIOENERGY PRODUCTION

Like all other industries, the bioenergy industry and supply chain must transform into a completely fossil-free production. The energy needed for the collection of biomass in the forest, for cultivation of energy crops in agriculture, for transport and processing, as well as all other auxiliary energy must be fossil-free. The ambition should be fossil free machinery, off-road vehicles (tractors, harvesters, etc), and fossil free transport by 2030.

The auxiliary energy required to produce biofuels is very modest compared to the energy content of the fuels, but this is not an argument for refraining from a total conversion so that no fossil fuels are used in the supply chain. The bioenergy industry should not contribute to fossil carbon dioxide emissions at all.

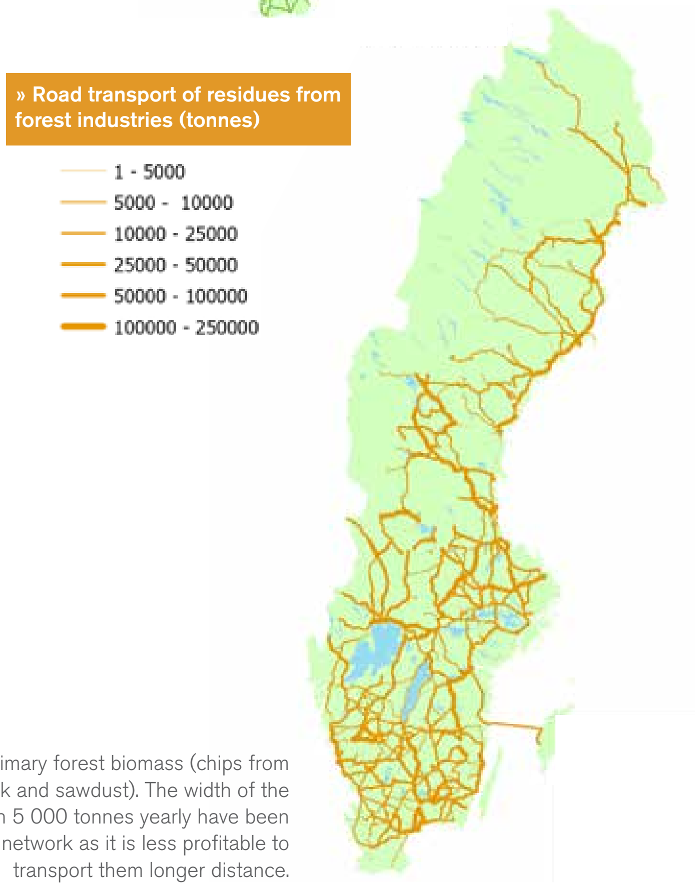
In the case of other greenhouse gases, the situation is more complex. Cultivation of energy crops is hardly possible if the requirement is zero emissions for nitrous oxide and methane. All cultivation produces certain emissions, which can be seen as part of the natural carbon cycle. Through better cultivation technology, emissions can be kept lower. It should also be noted that the result of cultivation is a very large absorption of carbon dioxide.

The changeover has already begun. A few examples are the companies Södra and Lantmännen, whose goal is that all transport of raw materials and finished products should be fossil-free. The arable industries are major buyers of transport services and their conversion to non fossil fuels is an important part of the conversion of all heavy transport. The main alternative is to replace fossil diesel with biodiesel and other biofuels. Electrification is not a working alternative for these raw material transports, as they take place on the local and regional road network with no access to charging or electric roads. The expansion of terminals enables increased transport by train and boat. Heavier and longer trucks are also an important component for reducing energy consumption per tonne of biomass transported.

To make the cultivation of energy crops in agriculture fossil-free requires a conversion from diesel to renewable fuels such as biodiesel, bioalcohols and biogas.

Nitrogen fertilizers can be produced from renewable energy instead of today's fossil natural gas.

» FIG. 13 **DELIVERY OF BIOMASS IS HEAVILY DEPENDENT ON ROAD TRANSPORTS**



The maps show all roads transporting more than 5 000 tonnes of primary forest biomass (chips from slash, discarded wood)) and secondary biomass (by-products like bark and sawdust). The width of the lines indicates the transported volume. Roads transporting less than 5 000 tonnes yearly have been excluded. Transports of primary forest fuels use a lesser part of the road network as it is less profitable to transport them longer distance.

Illustrationer: Skogforsk

5. ECONOMICS AND THE MARKET FOR BIOENERGY

5.1 TRADE - IMPORT AND EXPORT

The trade in biomass fuels and raw materials for solid biofuels is essentially free. However, there are tariffs and other barriers for biofuels from outside EU.

When analyzing Swedish use of bioenergy, free trade must be taken into account. Fuels and raw materials from other countries can often have a significantly lower price than the cost of domestic production. It must be expected that the trade in biomass and biofuels will increase sharply in the coming decades.

Pellets can serve as an example for this development. Global production capacity is increasing fast, and is currently around 70 million tonnes of pellets (Bioenergy International pellets map 2019). Global consumption is around 30 million tonnes.

Pellets are an example of a new bioenergy product being developed into a global commodity. The trade in pellets will be facilitated by standardization and certification, publication of price indices, trading on commodity exchanges that enable forward trading etc.

A similar trend can also be expected in the trade in wood chips. Although wood chips are a less homogeneous product.

The potential for increased mobilisation of biomass is very high in countries in Sweden's vicinity, especially in Eastern Europe, where the utilization of forest raw materials as a proportion of forest growth is low, and where there are very large areas of abandoned and unused agricultural land.

Sweden imports a lot of bioenergy today, mainly in the form of waste and HVO diesel and raw material for biofuels. Sweden also imports recycled wood, wood chips and pellets, and simultaneously export ethanol and pellets. In the future, Sweden is likely to increase both imports, for example of cheap waste fuels and biofuels, and increase exports, for example of torrefied pellets, biochar, perhaps also forest-based biofuels for transport, such as biojet fuels.

Substitution of fossil fuels with Swedish fuels creates jobs and income around Sweden, but there is no self-purpose with 100 per cent self-sufficiency in bioenergy, as long as there is access to fuels on the world market at a low price.

Summary: Total use of bioenergy in 2018 was 162 TWh, of which imports accounted for 34.2 TWh, or 21 per cent. If the export of ethanol and pellets is included, the net import of biofuels was 31.6 TWh or 19.5 per cent. Note that the total amount includes all waste, i.e. also fossil waste.

TABLE 7, **IMPORT SHARE OF DIFFERENT CATEGORIES OF BIOMASS AND BIOFUELS 2018**

	USE (TWh)	OF WHICH IMPORT (TWh)	EXPORT (TWh)	IMPORT SHARE (%)
UNREFINED WOOD FUEL	56	2		4
REFINED WOOD FUEL	9	2	1	22**
RECYCLED WOOD	6	2		33
WASTE	22	6		27
BIO OIL	5	3		60
BIODIESEL HVO + FAME*	17,8	16,9		95
ETHANOL*	1,5	1,26	2	84***
BIOGAS*	1,4	1	-	29
PEAT	1			
BLACK LIQUOR	43	0		0
TOTAL	162,7	34,2	3	21

**Applies to the origin of the raw material, Source: Swedish Energy Agency, "Drivmedel 2018"*

***Sweden exported 0.9 TWh pellets at the same time in 2018.*

****The figure applies to the ethanol used on the Swedish market. At the same time, there is an export of about 1.7 TWh of ethanol, which means that Sweden has a net export equivalent to 13% of its use.*

Sources: Profu, Swedish Energy Agency, Svebio, PelletsFörbundet

5.2 RESTRICTIONS FROM THE EU

The EU, partly as a result of negative lobbying against biofuels, has imposed restrictions primarily on the utilization of biofuels from arable crops. There is a similar risk of future restrictions on the extraction of biomass for energy purposes from forest land. The view of bioenergy must become more positive and the focus of the incentives must change from today's restrictive view to recognizing the opportunities for the production of renewable fuels from agricultural and forest land. Generally, the view on waste incineration for energy recovery must also become more positive, an not as today be considered a last resort. Incineration with good fluegas cleaning is an important part of a circular economy where both material and energy resources are utilized.

In one respect, the EU has had a positive impact. The sustainability criteria for both liquid and solid biofuels adopted by the EU create confidence that biofuels can be produced sustainably.

Photo: Againity

A small cogeneration plant with ORC technology can also produce electricity in smaller heat plants.

5.3 SECURITY OF SUPPLY

Issues regarding security of supply, emergency preparedness and defense preparedness have received increased attention in recent years. In a 2016 report[30], the Defense Committee addressed the issue of reconstruction of emergency preparedness, an area that had been neglected during the post-Cold War period. Increased tension in our part of the world has put a new focus on the need for a secure supply of energy and food both in peaceful crises and in a war situation. Various sections of the report deal with electricity supply, heat supply and fuel supply.

Bioenergy has many advantages when it comes to preparedness. The fuels are domestic and often supplied locally or regionally. The district heating supply is dependent on electricity for operation and pumps, but it is possible to design the systems so that they guarantee the heat supply even in the event of disruptions in the national electricity supply. Even smaller heat plants can be supplied with their own electricity production, for example by using ORC technology. Small-scale heating with biomass (firewood, woodchips and pellets) already provides hundreds of thousands of households with heat and the possibility of cooking during a crisis.

30. Försvarsdepartementet, Motståndskraft, inriktningen av totalförsvaret och utformningen av det civila försvaret 2021 – 2025, Ds 2017:66.

5.4 THE COST OF BIOENERGY

A common comment both in Sweden and internationally is that there is not enough biomass. While this is a false statement, it has nevertheless become a widely held notion. One consequence of this general view is that no countries fully implement a policy that takes advantage of the potential of bioenergy to solve the climate and energy issues.

A common view is that it is impossible to grow enough food in the world, despite food production increasing faster than population growth at least since 1961. In Sweden and in the EU, arable land has been continuously taken out of production as well as in large parts of the rest of the world, mainly due to persistent low prices of agricultural products, which depend on surplus production globally and regionally.

Within the EU, there has been excess food production since the 1980s and the EU has since paid farmers not to produce, to leave part of their land fallow. At first, this was done to lower the surplus of grain as well as the surplus of meat and butter. Over the past decade, excess milk production has been an issue. In the second half of the 2010s, the EU, through the CAP (the common agricultural policy), has demanded that farmers have environmental fallow to reduce food production. At the same time, the EU is preventing the production of biofuels from arable land because it is alleged to indirectly cause rainforest deforestation. The argument is that someone else would grow the food that is not grown in Europe and do so on rainforest land!

If farmers were encouraged to grow energy on the surplus land instead, agriculture could contribute to reduced climate emissions in the same way as forestry to a significantly higher degree, as shown in the flow chart of the Swedish forest-bioenergy system in Chapter 3. Thus, there is a good supply of biomass for energy. When there is a demand for biomass, the price rises and more raw material will be produced in existing production systems and on existing land. If demand exceeds supply, the price increases and other renewable energy becomes more interesting. This will also increase the competitiveness of energy efficiency, electric cars and other alternatives.

5.4.1 Unprocessed solid biofuels

The price for unprocessed biomass as raw material has so far varied from a negative price for unsorted biogenic waste, i.e. that one is paid to receive waste,

Today, the heating plants pay SEK 175 - 200 per MWh for wood chips.

to a maximum of SEK 230/MWh for wood chips for larger buyers. The Swedish Energy Agency regularly reports (four times a year) on the price level that has been applied in the market. In 2019, according to the Swedish Energy Agency, the price was between SEK 175 and 200 per MWh for wood chips and industrial by-products. The price of recycled wood has been about SEK 100 lower per MWh than for wood chips and by-products.

This roadmap identifies stumps as a potential for increased biomass volumes. Today, the cost of harvesting stumps is probably around SEK 250/MWh, or above. Large-scale trials and tests have been carried out to establish that stumps can become a suitable fuel and can be harvested with biodiversity consideration. However, in order to achieve technology and logistics development, much larger harvest volumes are required. Therefore, harvesting of stumps will probably be done at a cost equivalent to forest chips, provided the volumes increase.

UNPROCESSED SOLID BIOFUELS:

SEK 100/MWh = 10 ÖRE/KWh

5.4.2 Refined solid biofuels

The price of refined fuels such as pellets and briquettes is around SEK 300/MWh for large consumers.

The price of solid biofuels can be compared to the prices of fossil fuels. A crude oil price of USD 65/barrel, when the dollar is SEK 9.4, means an energy price of SEK 360/MWh. The price of coal in 2019 was USD 55/tonne, which gives an energy price of only SEK 53/MWh, which is lower than for recycled wood. In recent years, a more normal coal price has been around USD 80 - 100/tonne, which corresponds to SEK 87/MWh. The natural gas price is around SEK 150/MWh. The reported prices of biomass from the Swedish Energy Agency quoted above are prices for fuels delivered to heat plants, while the prices of coal and oil are quoted world market prices.

In summary, it can be said that the price of biomass is similar to that of fossil gas, but lower than that of oil and higher than the price of coal. In order to compete with coal and gas, a price on carbon dioxide emissions is required via emission allowances or a carbon dioxide tax. Compared to oil, there is already competitiveness without a carbon price. However, it must be taken into account that more expensive equipment is required to burn solid fuels than oil. The lower energy density for biomass compared to fossil fuels requires larger fireplaces, and cheap biofuels, such as recycled wood, often require more expensive fluegas cleaning to remove contaminations.

Cultivated biomass has a higher cost than by-products and residues.

It is more difficult to do a socio-economic analysis than a business economics analysis. Imported fossil fuels may have a lower price, but the entire flow of money goes abroad. If you buy domestic fuels, a large part of the money stays in the country and is used for investment, labor, transport and taxes in Sweden.

One saying is that 1 TWh bioenergy leads to 300 direct jobs and another 100 indirect jobs. The shift from heating Sweden's cities with close to 100 per cent oil and coal in the 1970s to biofuels, waste heat and waste today has not only provided tens of thousands of Swedish jobs, but also tens of billions in better trade balance and billions in increased tax revenues.

5.4.3 Bio heat

The price of Swedish district heating is currently around SEK 700/MWh. Since the main fuel type is biomass, this can be regarded as a guide value for the price of bio-heat. The cost is allocated to cost of fuel, distribution networks and heating plants (operation and capital cost of the investment). The price also includes 25 per cent VAT.

5.4.4 Biopower

The cost of producing biopower varies with the size of the plant. According to Energiforsk's (Elforsk's) latest calculations, the cost is just over SEK 0.70/kWh for a 30 MW cogeneration plant based on a 6 per cent interest rate. The actual cost depends to a large extent on the number of hours during which the plant has the opportunity to sell electricity and heat and thus distribute the cost. For smaller plants, the cost is higher, and for larger plants, the cost is lower. Once the investment is made, the owner of the plant primarily looks at the marginal cost, which consists of fuel cost and other variable costs, to decide whether to produce biopower or heat alone.

If the electricity price is high enough, running condensation without using the heat can pay off. The cost of electricity production in condensing operation depends on the electrical efficiency rate and the fuel cost. Cogeneration from waste results in a significantly lower cost per kWh, since the fuel cost is much lower, even negative. In addition, the operating time is longer because the waste is incinerated on a year around basis. The highest cost will be when using refined fuel such as pellets or bio-oil for condensation production. Then the cost can be SEK 1.00 - 1.50/kWh depending on the price of bio-oil.

Having cogeneration plants in cities that produce electricity when it is not windy is a very cost-effective alternative to new nuclear power, even if the plants are sometimes run as condensation power units. The new nuclear power plant being built in Hinkley Point in the UK will receive a guaranteed price of 95 pounds per MWh, which corresponds to SEK 1.17/kWh, indexed for 35 years from 2023 to 2058. This price applies to electricity generation from the nuclear power plant during all hours of the year for 35 years.

In Sweden, the electricity prices are almost never as high as the prices needed to cover the costs of the contract with Hinkley Point. A significantly more efficient method of meeting the need for electricity is to produce power with cogeneration and in cases where cogeneration is not sufficient with biocondensing power. This can be done at a similar cost per kWh as in Hinkley Point, but with the advantage of producing expensive electricity only the few hours it is needed.


Ethanol is by far the most important biofuel for transports, in volume, in the world. Three quarters of all biofuels consumed are ethanol.

5.4.5 Biofuels for transport

The cost of biofuels for transport varies greatly depending on the raw material, technology and the type of biofuel produced. Compared to today's fuel prices to consumers, the cost of biofuels is not high, but in fact lower. However, the cost of biofuels is higher than the cost of fossil fuels without tax. It is important to distinguish between cost and price that can differ greatly in the oil and fuel industry.

The cost of ethanol production from grains in Europe is around SEK 5 - 6/liter. The cost of ethanol production from sugar cane is up to SEK 2 lower, while ethanol production from cellulose is more expensive but has the potential for reduced costs as volumes increase. To compare the ethanol cost for E85 with petrol (with 5 per cent ethanol blend), the above cost must be multiplied by about 1.35. The world market price of ethanol listed in Chicago in January 2020 is SEK 3.4/liter, which is equivalent to SEK 5.2 per petrol equivalent. Thus, it is not associated with a particularly high cost to significantly reduce Swedish carbon dioxide emissions by switching imported petrol to imported renewable ethanol in the form of E85.

Of course, a reasonable level of European and Swedish ethanol production should be safeguarded in such a shift.

The cost of biodiesel also depends primarily on the raw material used. The cheapest oils used when producing biodiesel are waste oils such as animal fatty acids from the food industry, PFAD (Palm Fatty Acid Distillate – an inedible residue from palm oil production), and used cooking oil, UCO.

Examples of other vegetable oils are rapeseed oil, soybean oil and corn oil, all of these crops also provide protein feed. Palm oil can also be used directly for diesel production. The cheapest way of producing biodiesel is by esterifying the vegetable oil into a methyl ester, such as RME, rapeseed methyl ester. RME can be run directly in an adapted diesel engine.

In recent years, it has been possible to refuel HVO diesel, Hydrated Vegetable Oil, in Sweden. It is a renewable diesel that functions like a regular diesel and no engine adjustments are needed. Driving a regular diesel car on HVO100 is therefore now one of the best ways to get a completely fossil-free car. The cost of RME is SEK 7 - 8/liter (the energy content comparable to ordinary diesel), while the cost of diesel made from waste oils such as animal fatty acids, PFAD and UCO is SEK 5 - 6/liter. The cost of biofuels from forest raw materials in a new factory is SEK 10 - 12/liter. What the prices will be if the demand increases is difficult to answer.

It is likely that prices will not rise much above SEK 12/liter, plus distribution and taxes. During winter/spring 2020, the cost for HVO at the gas station was SEK 17.50/liter where SEK 3.50 is VAT. This price level gives the biofuel producer a good profit and drives new investments. It also increases the price of raw material, which results in players trying to get more raw material. The waste oils mentioned above can be compared to fossil oil from Saudi Arabia or Texas. It is easy to pump up at low cost and gives a good profit. Since the oil produced at low cost in Saudi Arabia and Texas is not sufficient for the global demand, Norwegian offshore oil also has a market, despite its higher cost. The Norwegian oil can be compared to cultivated crops which produce a more expensive vegetable oil than the waste oils. Finally, we have forest raw material, which is a cheaper raw material but it is more expensive to process fuel from it. Producing biofuel from forest raw materials can be compared to making petrol and diesel from coal.

Just like the cost of food production has decreased per kilo in real terms, the cost of biomass and biofuels will also decrease over time. Svebio's view is that the amount of biomass from agriculture and forest raw materials is not limited in relation to efficient global energy use. But of course, an active production of biomass for energy use is required for the volumes to be sufficient.

In the long term, it is the cost of making cellulosic fuels for transport that will be setting the global price of biofuels. In the future, the cost of producing a petrol or diesel equivalent should fall below 1 euro per liter in the 2020 monetary value, even for the more costly processes from cellulose.

The fact that costs for biofuels can be kept relatively low is confirmed in the research made by Pål Börjesson and Joakim Lundgren who updated the governmental report from 2013: "Fossilfrihet på väg".[31] However, the price of biofuels may from time to time be significantly higher depending on demand and production capacity.

In summary, it can be said that policies should be designed with general incentives without restrictions on the availability of biomass. The supply is not unlimited but the potential is very large and will be limited by what is technically, economically and environmentally sustainable.

Producers of biofuels must comply with regulations and legislation applicable to forestry and food production. If you follow the principles published by the Swedish authorities on, for example, biodiversity and the preservation of carbon in agricultural land and forest at the landscape level in the publication "Bioenergi på rätt sätt" and in addition apply the renewable energy directive's sustainability criteria, there are good possibilities for a large increase of sustainable bioenergy production.

Replacing all fossil aviation fuel that are refueled in Sweden would require 12 TWh non fossil biojet fuel per year.

31. Börjesson P, Lundgren J m fl: Dagens och framtidens hållbara biodrivmedel i sammandrag, f3center 2016.

6. ACTIONS NEEDED

In order to mobilize the potential of 250 TWh biomass as a contribution to climate change mitigation, actions are needed by many actors. Actions by the government and parliament, authorities, regions, municipalities, business, academia and individual consumers are needed. Not least, a positive view in the EU of bioenergy as a renewable energy source is needed.

6.1 OUR OWN COMMITMENTS

The bioenergy companies are companies from a number of industries with their own roadmaps and commitments. District heating companies, transport companies and fuel producers all have their own plans to phase out fossil fuels in their sector. This Roadmap Bioenergy, showing the possibility of delivering sustainable bioenergy, is therefore slightly different from other roadmaps for a fossil-free Sweden.

The industry is prepared to develop technology, markets and environmental performance, to make the production chain fossil-free and to cooperate with others to achieve the targets. Our commitment is to do this with retained and increased biodiversity and with the return of nutrients to fields and forest to uphold production capacity. Bioenergy production is to take place without hazardous emissions and with a competitive economy.

6.1.1 Environment and sustainability

» Apply the sustainability criteria in the EU directives, Swedish sustainability legislation, Swedish environmental and forestry legislation, and the EU's common agricultural policy, as a guarantee that the biofuels we produce and use have high environmental performance. Biomass and Biofuels should come from sustainably used forests and fields.

» Use modern technology to reduce emissions of harmful substances and strive for "near-zero emissions" combustion. Bioenergy should be clean energy that does not adversely affect health and the environment.

» Old technology must be replaced with modern technology. For example, older wood boilers should be replaced with modern equipment that meets the EcoDesign requirements.

» Eliminate the use of fossil fuels in our own production chains, for example for transport and processing, in order to guarantee a fossil-free delivery to customers.

» Our objective must be to return all clean wood ash to forest land to improve the recycling of plant nutrients. Work for the extraction of phosphorus from ash that cannot be directly returned. Increase recovery of ashes and ensure that hazardous ashes are handled safely.

6.1.2 Energy efficiency and trade

» Streamlining of biofuel boilers and system solutions to increase the efficiency from fuel to delivered energy, and thus conserve biofuel resources.

» Develop technology for higher electrical efficiency rates in cogeneration, biopower technology for small-scale applications and bio-based solutions that provide balance power in a 100 per cent renewable electricity system with a large proportion of variable electricity generation.

» Develop logistics to reduce costs and facilitate the mobilization of biomass from all parts of Sweden.

» Develop biofuel trade through standardization, certification and construction of trading venues. Counteract trade barriers.

6.2 REQUESTS TO GOVERNMENT AND GOVERNMENT AUTHORITIES

6.2.1 The supply of bio raw material

» Work to lift EU restrictions on the use of bio-raw material from arable crops that could be used as food or animal feed.

» Work to utilize unused arable land for biomass production for energy purposes. Take advantage of the opportunities under EU agricultural policy to support the planting of energy crops, such as salix and poplar.

» Draw conclusions from the research program on stumps for energy, and work for harvesting of stumps.

» Implement a practical operation of the Renewable Energy Directive's sustainability criteria for solid fuels, so that biomass from forest can be utilized rationally and in an environmentally friendly way.

» Allow heavier and longer trucks and trains for advanced logistics that reduce transportation costs for bio raw materials and biomass fuels.

» Develop a climate-adapted responsible peat production, using already drained peat lands with high greenhouse gas leakage to restore them as carbon sinks after peat harvest.

6.2.2 Bio heat market

» Safeguard and develop district heating and cogeneration. Implement those parts of the energy agreement from 2016 between a majority of the political parties which states that district heating should be promoted and that electric heating should be reduced.

» Design the building code so that district heating and bioenergy solutions are not disadvantaged in relation to electricity-based heating with heat pumps.

» Provide support for the expansion of local district heating networks.

» Stimulate increased use of high-efficiency pellet stoves to reduce power peaks in electricity consumption.

» Design incentives that counteract high load demand from the households.

» Reduce emissions from small-scale wood burning by introducing a support for conversion from older to modern biomass firing equipment that meets the EcoDesign requirements.

6.2.3 Biopower production

» Let the electricity producers pay a certain fee for the electricity infrastructure they use in relation to how far the electricity must be transported to reach the customer. All power producers must pay for the infrastructure they use.

» Design incentives or pricing mechanisms that favour investments in bio-cogeneration in larger urban areas, to counter capacity shortages in local and regional electricity supply.

» Investigate the capacity issue in a 100 per cent renewable power system with a high proportion of variable production. Procure renewable capacity and power reserve to manage electricity supply.

» Provide increased support for the development and demonstration of technology for biopower production with higher electrical efficiency rates, for example with gasification technology.

» Provide support for the development of small-scale biopower technology.

» Develop waste incineration so that materials that should not be recycled can be destroyed, such as plastics and recycled wood, as these may contain contaminants such as heavy metals, solvents, hormone disrupting substances, etc. Eliminate the waste incineration tax.

6.2.4 The market for biofuels for transport

» Steer the market with general incentives based on the climate impact, first of all by putting a price on carbon dioxide emissions.

» Increase the quotas within emissions reduction obligation system, so that the 2030 target is reached and that a fossil free transport sector is achieved by 2045.

» Work for extension of the tax exemption for high blends and clean biofuels.

» Eliminate targeted support that distorts competition between various technical solutions, such as the electric bus subsidy.

» Eliminate bonus / malus and steer through the taxation of fuels. If bonus / malus is maintained, it should be reformed with the following orientation:

  • Bonus for all vehicles that show high climate benefit. This means, for example, that support should be given to efficient diesel vehicles where the owner can show that the vehicle is refueled with clean biodiesel.

  • Bonus for flexifuel cars (for ethanol) in the same way as for biogas cars.

  • Conditional support for Plug-in Hybrid vehicles with these being flexifuel and refueled with renewable fuel.

» Introduce a conversion support so that existing petrol cars can be rebuilt for operation with E85.

- Immediately introduce E10 on the Swedish market as standard petrol and work for a transition to E20.
- Stimulate domestic production of biofuels through support for research, development and demonstration and through targeted support that enables the construction of full-scale production facilities.
- Introduce a reduction quota for aviation biofuels and increase the quota according to a linear curve 2021 - 2030. Establish an indicative quota curve for the period after 2030 as well.
- Investigate the possibilities of introducing a sub-quota for ligno-cellulosic biofuels within the reduction quota for road transport fuels and aviation fuels.
- Design a policy instrument that enables fossil fuels to be replaced with biofuels intractors and machines in the arable industries (farming and forestry).

6.2.5 The market for biofuels in the industry

- Provide support for technology development for fossil-free production and develop “the industry climate leap” to include more industries and companies. Use “the climate leap” (support for local and regional climate initiatives and investments) primarily to enable conversions that would not be achieved on commercial grounds.
- Promote increased price levels within the EU Emissions Trading Scheme (EU ETS).
- Implement a project for fossil-free steel production using biocoal as raw material in order to be able to make a comparative technical / economic evaluation in relation to the Hybrit project. Hybrit aims to replace coking coal, traditionally needed for ore-based steel making, with hydrogen. The result will be the world’s first fossil-free steel-making technology, with virtually no carbon footprint.

6.2.6 Other

- Work for large-scale demonstration of bio-CCS, first at a larger cogeneration plant using biofuel or waste, or at a larger pulp mill. Design instruments that make bio-CCS possible, for example by linking emissions trading.
- Improve bioenergy statistics, both for supply, production and use.

6.3 REQUESTS TO MUNICIPALITIES AND REGIONS

- Prioritize district heating when planning local communities and housing. Build primarily for district heating in all new residential and industrial areas.
- Investigate the possibilities of local electricity generation from biofuels if bio-based cogeneration is not already available.
- Develop insular supply operation for the local electricity and heat supply to reduce vulnerability in crises and major power outages.
- Make sure that public transport is fossil-free, as is your own vehicle park.
- Ensure that residual waste after material recycling is used in an optimal way for energy recovery, for biogas production and for electricity and district heating production.

6.4 REQUESTS TO TRADE AND INDUSTRY

- Invest for a fossil-free production, distribution and raw material consumption. Make a correct and fair assessment of available alternatives, primarily biofuels or electrification.
- Take advantage of the opportunities available for counseling and state aid, for example through ”the climate leap”.
- Investigate the possibilities for energy production for own needs, using, for example, biogenic residues, or small-scale electricity generation.
- Develop trade in biofuels through standardization, certification and increased transparency, for example through stock exchange trading. Develop better pricing information.

6.5 REQUESTS TO INDIVIDUAL CONSUMERS

- Use modern biofuel heating equipment to provide the lowest possible local emissions.
- Use dry wood or wood chips without pollutants or pellets that meet European standards or are ENplus certified.
- Install heating equipment that can withstand long-term power cuts and reduce the need for electricity when cold, to reduce the power load on the local grid.
- Investigate the possibility of own electricity production from biomass.

6.6 REQUESTS TO THE EU

- Work towards a pricing of carbon dioxide in all parts of the economy. Strengthen the targets within the ETS and revise the Energy Taxation Directive with the purpose of introducing a common minimum tax on carbon dioxide emissions in all sectors outside the ETS.
- Take a positive view on the mobilization of biomass from arable land and lift restrictions on "food and feed" raw material.
- Remove all types of double counting and create “level playing fields”. Artificial politically created values cause fraud and cheating.
- Give bioenergy the same support for funding through the EU's taxonomy proposal as other renewable energy types. Do not introduce new criteria that make it difficult to assess the climate and environmental benefits of bioenergy. Make sure that energy recovery from waste also becomes part of the taxonomy.
- Promote free trade on equal terms regarding bio raw materials and biofuels that meet EU sustainability criteria for optimal utilization of global bioenergy resources.
- Sharpen the targets for a climate transition of the transport sector.
- Introduce EU common incentives for biofuels in aviation and shipping within the EU.

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