# Strategy for fossil free competitiveness

## BIOENERGY AND BIO-BASED FEEDSTOCK IN INDUSTRY TRANSITION

Fossil Free Sweden

A strategy by
Fossil Free Sweden

# Table of contents

# The pace of transition must be accelerated!

To facilitate implementation of the 22 roadmaps for fossil free competitiveness produced by the industry sectors, Fossil Free Sweden is now working to develop strategies in collaboration with various companies in the respective value chain. We previously developed strategies for both a sustainable battery value chain and hydrogen development, and have now set our sights on bioenergy and bio-based feedstock, which can contribute to several sectors becoming fossil-free.

Bioenergy, which is Sweden's largest source of energy, has been a key factor in reducing Sweden's greenhouse gas emissions by 29 percent compared to 1990 in the official statistics. Bioenergy will continue to play a crucial role in the rapid phase-out of fossil feedstock in Sweden and the EU, including in what is predicted to be a very rapid electrification of the transport sector.

This bioenergy and green carbon strategy that you now hold in your hands does not aim to resolve all the interesting and important issues that are now shaping the discussion, such as how much removal from forests is sustainable or how much agricultural land can be used to replace fossil resources.

Instead, the primary aim is to show how the puzzle of the 22 roadmaps will fit together. According to our assumptions, the total need for bioenergy and bio-based feedstock expressed in the roadmaps would require a significant increase in biofuel imports.

It may seem strange and unsustainable that a leading country like Sweden with a relatively large amount of forest would suck the market dry of biofuels in order to meet the Swedish climate goals. This strategy instead shows that efficiency improvements, new technology and increased refinement of Swedish bio-based feedstock with the help of the price mechanism can increase Swedish exports of technical solutions and bio-based products so that emission reductions can be accelerated in other countries as well.

Presenting a bio-strategy is a bit like walking into a minefield. The subject is extremely complex, and new research is emerging all the time. An underlying aim is therefore to also bring more balance to the bioenergy issue, thus preventing increased polarisation from slowing the pace of political decision-making and pure investments at a time when we actually need to accelerate the pace to become fossil-free quickly.

In its coordinating role, Fossil Free Sweden has tried to find a stable common denominator in how Sweden can achieve a credible narrative on the changing role of bioenergy and bio-based feedstock over time as different roadmaps are implemented. The dialogue with the various companies and sectors in the value chain has been extremely constructive, with everyone having to give and take in order to take some common steps forward. It is always a difficult challenge for companies and sectors when the market is changing due to factors such as rapid electrification, higher emissions prices, and expected price increases for bioenergy.

I hope this strategy can lay the foundation for accelerating the phase-out of fossil feedstocks and contribute to a different tone in the conversation on the role of bioenergy in a fossil-free Sweden and EU.

**Svante Axelsson**
National Coordinator, Fossil Free Sweden

# Companies behind the strategy

Fossil Free Sweden has had a dialogue with a number of companies and organisations, which support the strategy as a whole, but not necessarily all the individual formulations and proposed measures.

**Alarik Sandrup,** Director of Public and Regulatory Affairs, Lantmännen

**Alf Engqvist,** MD, Göteborg Energi AB

**Anders Egelrud,** MD, Stockholm Exergi

**Anders Ericsson,** CEO, Adven AB and Värmevärden AB

**Anders Fröberg,** MD, Borealis

**Anders Östlund,** MD, Öresundskraft AB

**Andreas Teir,** MD, Neste Sverige

**Christian Schwartz,** MD, Mölndal Energi AB

**Dag Waldenström,** Secretary General, Svenskt Flyg

**Håkan Carefall,** MD, Sala-Heby Energi AB

**Lotta Lyrå,** MD and CEO, Södra

**Lovisa Fricot Norén,** Director, Värme Sverige Unit, Vattenfall

**Magnus Heimburg,** MD, Preem

**Maria Fiskerud,** CSO, Braathens Regional Airlines (BRA)

**Mattias Bergman,** MD, Bil Sweden

**Per-Anders Tauson,** MD, E.ON Värme Sverige AB

**Per-Arne Karlsson,** Director of Public Affairs, St1 Sverige

**Rikard Engström,** MD, Svensk Sjöfart

**Sezgin Kadir,** MD, Kraftringen AB

**Ulf Larsson,** MD and CEO, SCA

# 22 roadmaps for fossil free competitiveness

In the roadmaps for fossil free competitiveness 22 sectors describe how they can contribute to the Swedish climate target of climate neutrality by 2045. Together they also show in what key areas decisive action needs to be taken in order to succeed with the transition in a way that strengthens competitiveness. Because of that, Fossil Free Sweden has developed horisontal strategies together with the actors in the the different value chains to pave the way and show the road ahead.

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|---|---|---|---|---|---|
| CONCRETE INDUSTRY | AVIATION INDUSTRY | CEMENT INDUSTRY | AGRICULTURAL SECTOR | MINING AND MINERALS INUSTRY | STEEL INDUSTRY |
| SKI RESORT SECTOR | DIGITALISATION CONSULTANCY INDUSTRY | FOOD RETAIL SECTOR | HEAVY ROAD HAULAGE | HEATING SECTOR | MARITIME SECTOR |
| AGGREGATES INDUSTRY | CONSTRUCTION AND CIVIL ENGINEERING SECTOR | ELECTRICITY SECTOR | FAST-MOVING CONSUMER GOODS INDUSTRY | RECYCLING SECTOR | FOREST SECTOR |
| AUTOMOTIVE INDUSTRY LIGHT VEHICLES | AUTOMOTIVE INDUSTRY HEAVY VEHICLES | PETROLEUM AND BIOFUEL INDUSTRY | GAS SECTOR | | |

# Summary

Together with electrification and efficiency improvements, bio-based feedstocks are a key component in replacing fossil feedstocks and fuels in the transition to a fossil-free Sweden. Bioenergy is currently the largest source of energy in Sweden and is the main reason why Sweden has reduced its territorial emissions of carbon dioxide by 29 percent in official statistics since 1990. In order to achieve the phase-out of fossil energy, the use of bioenergy will continue to increase, both in Sweden and within the EU.

The good availability of bio-based feedstock in Sweden offers great opportunities in various sectors to replace fossil feedstocks while strengthening competitiveness. However, like many other inputs, bio-based feedstock is a limited resource. It is therefore important to increase the value added to the resources in order to develop the bioeconomy in Sweden, while at the same time leading to efficiency improvements and the development of alternative solutions when bio-based feedstock becomes too expensive to use.

The purpose of this bio-strategy is to show how the market and policy, through factors such as the price mechanism, contribute to solving the high demand for bio-based feedstock that has emerged in the 22 roadmaps for fossil free competitiveness. The strategy identifies obstacles and challenges to the efficient use of the energy crops and the residues and by-products of agriculture and forestry, and highlights opportunities to use other fossil-free alternatives where possible, so that exports to other countries can be increased. The goal is to enable the realisation of the potential of bio-based feedstocks in the climate transition and implementation of the roadmaps.

## A possible solution to the puzzle

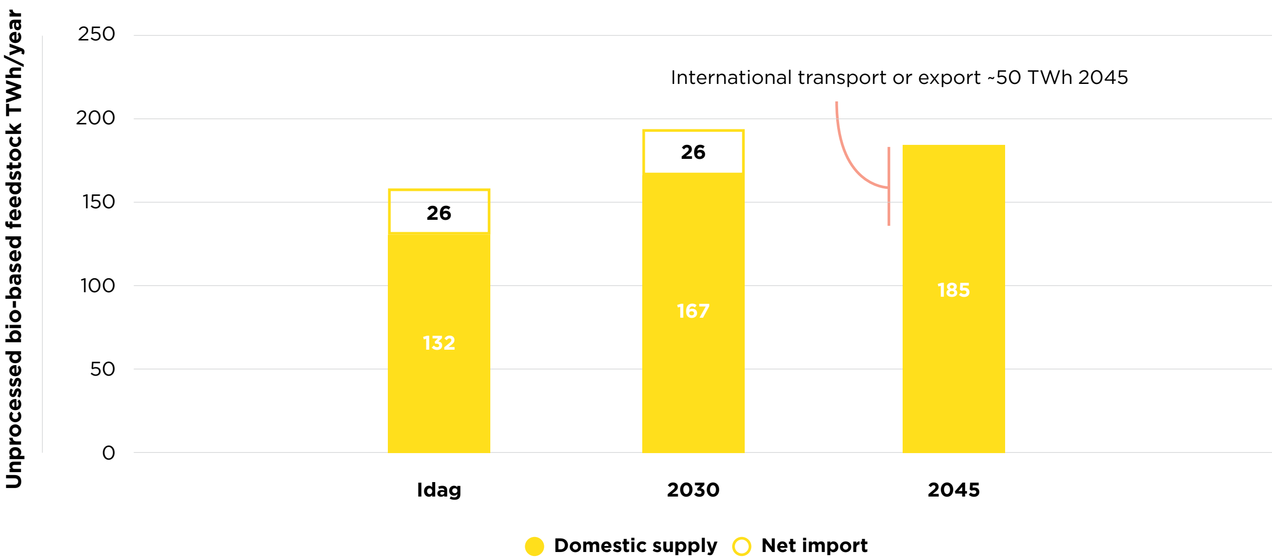
Many sectors point to the increased use of bio-based feedstock in their roadmaps as an enabler of fossil freedom, but if the increased demand is tallied together, it exceeds the amount of Swedish bio-based feedstock available for energy purposes (mainly estimated based on the report "Potential för ökad tillförsel och avsättning av inhemsk biomassa i en växande svensk bioekonomi" [Potential for increased supply and sale of domestic biomass in a growing Swedish bioeconomy] by Pål Börjesson of Lund University), which is not sustainable if Sweden is to be an international role model.

Current bioenergy usage is about 158 TWh, of which 26 TWh is imported as biofuels, mainly for the transport sector. Estimates based on the future needs expressed in the roadmaps for fossil free competitiveness are expected to increase to 241 TWh by 2045, which would require large imports. This bio-strategy shows how this challenge can be met through measures such as accelerating the electrification of the road transport sector, efficiency improvements and technology development in the heating sector, and efficiency improvements and electrification in the forest industry, all while creating opportunities for increased export.

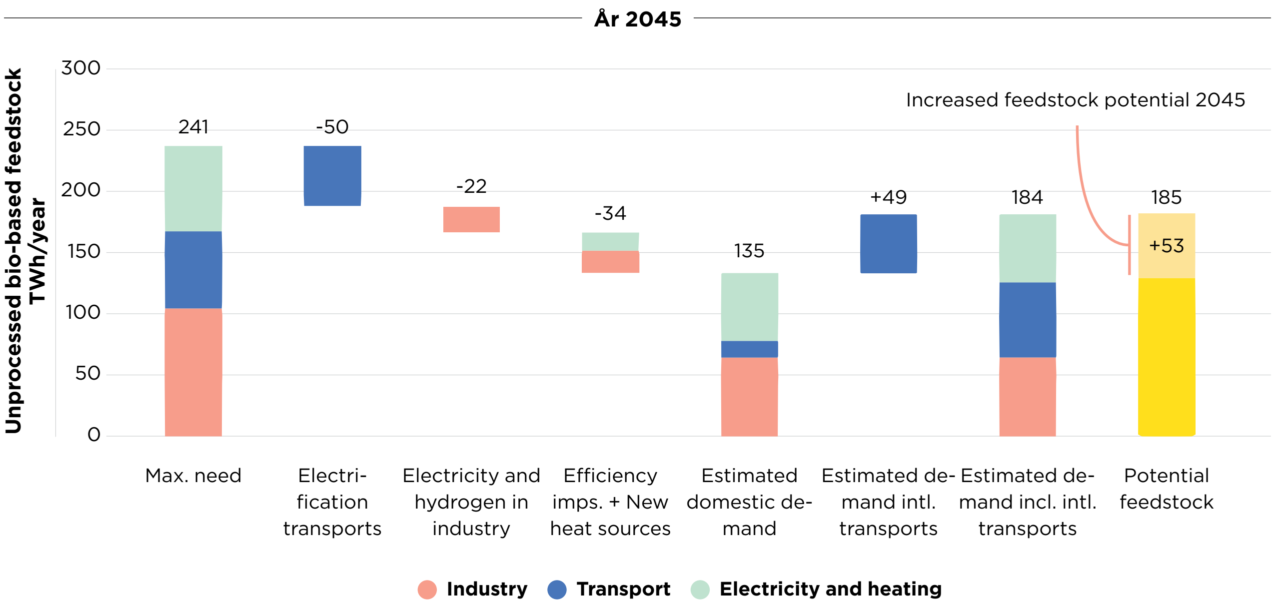
By 2030, this bio-strategy estimates that the need for bio-based feedstock will increase to around 193 TWh, which is an increase of 22 percent compared to the current use of bioenergy. The increase is largely due to the road transport sector's need for biofuels to meet the target of reducing emissions from domestic road transport by 70 percent compared to 2010. This means that imports of biofuels at this time are expected to remain at current levels, but represent a smaller share of total biofuels, as an increase in domestic production is planned.

By 2045, it is anticipated that electricity will be the dominant fuel in the road transport sector, while aviation and maritime transport will have an increasing need for biofuels. A large part of industry is expected to become fossil-free by 2045 through electrification and hydrogen technologies. Industry's need for bio-based feedstock may nevertheless increase slightly because the chemical industry in particular is likely to carry out much of its transition after 2030 and will only then have an increased need for renewable feedstock for its products. The development of the use of biofuels in the heating sector is expected to be largely driven by price developments, increasing the possibility that alternative technologies such as deep geothermal energy, solar heating, and increased use of waste heat will become more competitive and may account for a larger share of the energy supply in 2045. Increased energy efficiency in housing will also reduce heating demand in the future.

By 2045, domestic demand is estimated to be around 135 TWh, which means that Sweden is no longer expected to be dependent on imports of bio-based feedstocks for energy purposes, although this does not




Current use of unprocessed bio-based feedstock compared to estimated total need by 2030 and 2045. International transport includes the aviation and maritime transport, and is estimated to be supplied with domestically produced fuel by 2045.




Estimated need for bio-based feedstock in unprocessed form 2045. No net import is assumed. The maximum need is based on roadmaps and published studies.

exclude imports and exports of either feedstocks or products. Instead, there are opportunities to use large proportions of the fuel used to fill tanks in Sweden for international transports, such as aviation and maritime transport. Something that is not included in the initial demand of the roadmaps. Another possibility is export based on Swedish bio-based feedstock. The total estimated demand for bio-based feedstock in 2045 would then be about 184 TWh, which is a 16 percent increase compared to today's use.

### Key premises for sustainable supply and use of bio-based feedstock

The use of bio-based feedstocks has an important role to play in climate change mitigation. In a future bioeconomy, strict sustainability criteria will be crucial to maintain and increase the value of bio-based feedstocks. The sustainability of each individual value chain must be assessed, all the way from production to end use, regardless of the fuel used. The bio-strategy therefore highlights some key premises for sustainable supply and use of bio-based feedstock:

- **Substitution – bio-based feedstock must replace fossil feedstock and be used efficiently.** Bio-based feedstock can replace fossil feedstocks and thereby reduce fossil greenhouse gas emissions. Emissions from the use of bioenergy must always be compared with how the same purpose would be satisfied through other energy sources, including efficiency improvements and conservation, where the emissions of the entire value chains are included. To maximise the substitution effect, as much as possible of a felled tree, including its by-products and residues, should be used for products.

- **Land stewardship.** Land is a valuable resource that should be protected against irreversible exploitation. Sweden is a country where large areas of arable land is abandoned or left fallow. Thus, there is currently no conflict between the production of bio-based feedstocks and food production. However, the use of bio-based feedstock could have effects beyond the country's borders, and it is therefore important for there to be traceability of resources so that the whole sustainability picture can be assessed, regardless of whether the feedstocks are imported or produced domestically.

- **Carbon sequestration in a systems perspective.** An important prerequisite for bio-based feedstock to be considered sustainable is that it comes from a system where removal from forestry and agriculture does not exceed growth, but carbon sequestering instead increases over time. The reasonable system boundary is not the tree or the grove, but the national area for which Sweden has authority and is responsible for to the UN. Biogenic carbon dioxide is fundamentally different from carbon dioxide from fossil sources. Fossil extraction uses carbon that has been underground for millions of years, adding new carbon dioxide to the cycle when it is burned.

- **Sustainable bio-based feedstock takes environmental objectives into account.** How agriculture and forestry are conducted affects the possibility of achieving most of the Swedish environmental quality objectives. The EU Renewable Energy Directive (Directive 2018/2001) also contains sustainability criteria for solid, liquid and gaseous biofuels. A premise for the strategy is therefore that the supply of biofuels should always be within the scope of meeting set requirements and environmental quality objectives.

### Focus on by-products and residues, and increased use of abandoned land

This bio-strategy focuses on the supply and use of agricultural and forestry by-products and residues, i.e. bio-based feedstock outside the traditional forest industry and from agricultural food and feed production. In the case of agriculture, it also includes pure energy crops, such as energy forests and wheat and rapeseed, which are currently used for biofuel production. However, there is a strong dependence on the traditional forestry and agricultural value chains, as they will continue to be the economic drivers of forestry and agriculture.

Furthermore, the strategy assumes that future forestry harvesting levels will be similar to today's levels in relation to the growth of productive land. This means that forests will continue to increase their carbon stocks and act as a carbon sink, while harvesting levels can increase, assuming that forest growth increases as expected. However, this assumption may be affected by the European Commission's recent proposal to revise the

LULUCF Regulation. The proposal implies that Sweden, through natural carbon sinks, should increase its annual uptake of carbon dioxide from about 38 million tonnes to 47 million tonnes, which would probably have major consequences for Swedish forestry, resulting, among other things, in a reduction in harvesting.

The potential for increased use of bio-based feedstock from agriculture consists of both better use of residues from food production and increased production of energy crops on abandoned arable land. The availability of bio-based feedstock from agricultural land is based on the assumption that the area used for energy, food and feed production will be the about the same in 2030 and 2045 as it is today.

Sweden's ambition is to be the world's first fossil-free welfare country. With its large supply of bio-based feedstock, it can ensure that strict sustainability criteria are followed for the domestic bio-based feedstocks. In a changing world, the demand for bio-based feedstock is expected to increase, which also means there is an increased risk of losing biodiversity and other negative environmental impacts. Long-term sustainable bio-based feedstocks from Sweden can thus contribute to enabling a sustainable transition globally as well, and the strategy assumes that by 2045 Sweden will be a net exporter of bio-based products for energy purposes and industrial use outside of the traditional forest industry.

### Greatest willingness to pay in sectors with no other fossil-free alternatives

The increased demand for bio-based feedstock identified in the industries' roadmaps for fossil free competitiveness, together with policy instruments at both the national and the European level, will most likely result in increased prices. This will lead to bio-based feedstock being steered towards sectors with the greatest willingness to pay, which will probably be the sectors where relatively cheap fossil-free alternatives are not available. In the coming years, the greatest willingness to pay for bio-based feedstock is expected to be in the road transport sector. Although new car sales will be largely electrified by 2030, there will still be many internal combustion engines in the fleet that need continued access to sustainable, low-carbon fuels. In the longer term, bio-based feedstock is expected to be used, for example, as biojet fuel for aviation or as a renewable feedstock for the chemical industry.

If we are to achieve the goal of climate neutrality by 2045, there will have to not only be significant emission reductions, but also negative emissions. This can be achieved through bio-CCS, where biogenic carbon dioxide is captured and stored. Carbon capture technology is available today, but has relatively high costs and energy consumption. Plans for a Swedish market for negative emissions were recently presented by the Government, and bio-CCS may then also become an area of increasing willingness to pay for bio-based feedstock.

### Action plan

In several sectors, there are thus potentially cheaper alternatives to using bio-based feedstock to achieve fossil freedom. However, the maturity of the technology and the conditions for implementation vary between sectors and alternatives, and can therefore have different impacts. Although development is expected to be largely market-driven, there is also a need to introduce policy instruments in certain areas to accelerate or facilitate development.

In order to realise the potential of bio-based feedstocks from agriculture and forestry in climate change mitigation, Fossil Free Sweden presents the following prioritised proposals for increasing the added value for Swedish bio-based feedstocks. However, to enable the implementation of the roadmaps, solutions in other sectors will also be crucial to free up resources for areas where other alternatives are lacking. This bio-strategy therefore also highlights proposals for increased energy and resource efficiency and for an increased pace of electrification of society. An in-depth and complete list of all proposals is presented in Chapter 9.

**Prioritised proposals: Increased added value of Swedish bio-based feedstocks**

- In order to secure continued tax exemption for clean and highly blended biofuels, the Government should work to implement the European Commission's proposal to allow for this within the state aid framework (point 77 of the CEEAG). Until this change is in place, the current tax exemption should be extended. In the event that tax exemptions are not granted in the long term, one option is to include clean and highly blended biofuels in the reduction obligation.

- The Government should stimulate the domestic production of biofuels from lignocellulose, for example through an advanced quota in the reduction obligation, which should be possible to introduce in 2024.
- By 2022, the Government should set the blending levels in the reduction obligation for aviation kerosene for the years 2030–2045 and work towards equivalent targets in the EU. The final target should be 100 percent blending by 2045 in both cases.
- In 2022, the Government should introduce the targets for supplementary measures proposed in the Climate Policy Roadmap Inquiry's report (SOU 2020:4), where the target for bio-CCS is up to 10 million tonnes/year.

**Selection of other proposals:**

- In 2022, the Government should commission the National Board of Housing, Building and Planning, to develop building regulations that require the reporting of energy used instead of energy purchased when calculating the energy performance of a building, with the aim of steering the regulations towards more energy-efficient buildings. Incentives for self-produced energy remain important, but should be separated from energy performance regulations.
- In 2022, the Government should commission the Swedish Energy Agency to investigate the possibilities for increased utilisation of waste heat. The assignment could, for example, include amending the Electricity Act so that conditions set for system solutions can ensure that the residual energy generated in new plants is used to the maximum, removing obstacles to the recovery of waste heat, and putting instruments in place that encourage and provide incentives for adaptations of customer plants to enable lower temperatures in district heating networks.
- In 2022, the Government should commission the Swedish Energy Agency to develop an action plan with timetable and concrete milestones for electrification of light and heavy transport. The assignment should also include securing the infrastructure for passenger cars, heavy-duty vehicles and vessels. The action plan should include a needs analysis and proposals for measures to ensure there are charging points for heavy-duty vehicles at loading and unloading areas, in depots for overnight charging, public fast charging along major roads, and electricity supply and charging facilities at airports and ports.
- By 2022, the Government should set a planning target of 3 GW of installed electrolytic power by 2030 and at least 8 GW by 2045 to enable fossil-free development through hydrogen production and use in most sectors.

# 1. Introduction

Sweden aims to have zero net greenhouse gas emissions by 2045. As a step towards achieving this goal, 22 industries have developed roadmaps for fossil free competitiveness within the framework of Fossil Free Sweden.

In the roadmaps, the industries show how they will become fossil-free by 2045 with increased competitiveness, as well as what measures they themselves need to take and what political conditions are needed to accelerate the pace. The focus is now on implementing the roadmaps. To speed up this work, Fossil Free Sweden is developing horizontal strategies to address a number of challenges common among the industries.

Bioenergy, electrification and efficiency improvements are all key components in the transition to a fossil-free Sweden. Sweden is a sparsely populated country, 63 percent of which is covered by forest land and 6 percent by agricultural land.[2] Today, forests contribute to competitiveness, growth and export revenue through the forest industry's traditional products, such as wood products and pulp. Efficient use of land, residues and by-products from forestry and agriculture can significantly increase the value of these resources and help forestry and agriculture to further contribute to Swedish competitiveness and welfare.

One reason why bio-based feedstock has been identified as an important tool for the transition to fossil freedom is that switching feedstock or fuel is often already possible in the short term, without waiting for further research and technology development. Another reason is that the use of bio-based feedstock is now often cost-effective compared to other alternatives for transition. Biomass is a source of biogenic carbon that can be used to replace fossil carbon in various forms of products containing carbon, both as a material and as an energy carrier. These advantages mean that many sectors can and want to use bio-based feedstocks in the transition.

Bioenergy is currently the largest source of energy in Sweden and is the main reason why Sweden has reduced its territorial emissions of carbon dioxide by 29 percent in official statistics since 1990. Already today, Sweden's access to biomass offers opportunities to greatly facilitate the transition to fossil freedom, and strengthen competitiveness in a variety of sectors and industries.

In order to achieve the phase-out of fossil energy, the use of bioenergy will continue to increase, both in Sweden and in the EU. However, an increased demand for bio-based feedstock will cause prices to rise, and this limited resource will, in practice, not be enough for the transition without reprioritisation, efficiency improvements and the development of other potential fossil-free alternatives. The supply of Swedish bio-based feedstocks does not match the needs identified in the

**Biomass** is organic material found in a particular area, such as the biomass of a tree, regardless of whether it is used or not.

**Bio-based feedstock** is a raw product from biomass that can be refined.

**Bioenergy** is energy produced from biomass. Sometimes misleadingly used as future important applications do not use the feedstock for its energy content in particular. One example is the chemical industry, where the carbon atoms of the bio-based feedstock build the products in plastics and various chemical products.

**Biofuel is fuel** produced from biomass. It can be solid, liquid or gaseous.

**Vehicle biofuel** is fuel produced from biomass and used in transport.

To facilitate comparisons in this bio-strategy, the energy content of the bio-based feedstock is always presented using the unit TWh/year to account for the quantities of bio-based feedstock used in different sectors, even when the energy content of the bio-based feedstock is not the primary consideration.

roadmaps and several other scenarios for the transition to fossil freedom. The strategy tries to show how this puzzle can be solved by identifying obstacles and challenges for other fossil-free alternatives, where possible.

## 1.1 Implementation

The strategy has been developed at the initiative and under the leadership of Fossil Free Sweden. The work was carried out with the support of the RISE Research Institutes of Sweden and the industry sectors, and is based on knowledge gathered from literature, input from and discussions with specially formed reference and industry groups as well as other stakeholders from e.g. the forest industry, the iron and steel industry, energy companies, the chemical and refinery industry, and the environmental movement. The majority of the companies also support the strategy, as listed in the introduction.

The reference group consisted of: Christian Azar, Chalmers; Göran Berndes, Chalmers; Pål Börjesson, Lund University; Jonas Ericson, Swedish Environmental Protection Agency; Hillevi Eriksson, Swedish Forest Agency; Sören Eriksson; and Malin Lagerquist, Swedish Energy Agency.

The industry group consisted of: Johan G Andersson, Drivkraft Sverige; Helén Axelsson, Jernkontoret; Magnus Berg, Swedish Forest Industries Federation; Erik Dotzauer, Stockholm Exergi; Birgitta Govén, Swedish Construction Federation; Elin Hermansson, Hållbar Kemi 2030; Raziyeh Khodayari, Swedenergy; Jenny Näslund, Federation of Swedish Farmers (LRF); Karin Comstedt Webb, Cementa.

## 1.2 Purpose of the strategy

The purpose of this bio-strategy is to show how the market and policy, through factors such as the price mechanism, contribute to solving the high demand for bio-based feedstock that has emerged in the 22 roadmaps. The strategy identifies obstacles and challenges to the efficient use of the energy crops and the residues and by-products of forestry and agriculture, and highlights opportunities to use other fossil-free alternatives where possible, so that exports to other countries can be increased. The goal of the strategy is to enable realisation of the potential of bio-based feedstocks in climate change mitigation and implementation of the roadmaps.

It is important to point out that the aim is not to make a quantitative allocation of the amount of bio-based feedstock available. Instead, a qualitative assessment and analysis is presented based on the alternatives available in many sectors and their potential to influence the use of bio-based feedstock to make the roadmaps feasible. This will allow domestic demand to be met without the need for Sweden to use less sustainable feedstock, and will also enable the export of sustainable bio-based products, feedstocks and energy.

## 1.3 Key premises for sustainable supply and use of bio-based feedstock

The most important premise in a bio-strategy is that renewable resources should be used efficiently and that consumption should be in proportion to what nature can sustainably provide. The use of bio-based feedstocks has an important role to play in climate change mitigation. Strict sustainability criteria are therefore also important in a future bioeconomy. The sustainability of each individual value chain must be assessed and ensured, all the way from production to end use, regardless of which fuel is used. This chapter discusses a number of key premises for sustainable supply and use of bio-based feedstock.

### Substitution – bio-based feedstock must replace fossil feedstock and be used efficiently

Limiting emissions, both in the short and long term, is essential to achieving climate targets. In the shorter term, leaving forests standing increases their carbon sequestration. However, this has to be weighed against what the products produced from forest feedstock replace. Bio-based feedstock can replace fossil feedstocks and thus reduce fossil greenhouse gas emissions, which is called the substitution effect. For long-life products, such as structural timber, carbon dioxide is absorbed during the growth of a tree and then withheld from the atmosphere for the lifetime of a building. But even for short-life products from bio-based feedstock, such as fuels or solid biofuels, there is a clear climate benefit if they replace fossil fuels, as emissions of fossil carbon dioxide to the atmosphere are avoided. It is therefore an important principle to always compare the emissions from the use of bioenergy with a reference scenario, i.e. how the same purpose would have been satisfied with other energy sources, including efficiency improvements and conservation. The emissions of the complete value chains should be included, as required by the EU Renewable Energy Directive (Directive 2018/2001).

Another important principle is that bio-based feedstock should be used efficiently, so that the substitution effect is maximised. The more fossil products that are displaced, the higher the climate benefit. For this reason, as much of a felled tree as possible, including residues and by-products, should be used for products.

### Land stewardship

In Sweden, the EU and other countries with large areas of arable land that are abandoned or left fallow, there is no conflict between the production of bio-based feedstocks and food production. Instead, growing energy crops becomes a way of keeping the land open so it can be easily converted to food production if the need arises. However, in an international context and in view of soil erosion, soil depletion, building and other land-using consumption, arable land is a valuable resource that should be protected from irreversible exploitation. Land scarcity in other countries may also mean that the use of domestic feedstocks has an effect outside the country's borders where competition for arable land is fiercer. The traceability of resources is therefore extremely important, so that the entire sustainability picture can be assessed regardless of whether the feedstocks are imported or domestically produced.

So-called indirect land use change (ILUC) means that increased bioenergy production in one country can lead to land use change in other countries. For example, forests may be converted to agricultural land, with negative consequences for the climate. Another example is the use of land that was previously fallow, which may instead have positive consequences for the climate due to increased carbon sequestration in the soil. Multifunctional leys also have the potential to be used as protein feed, replacing imported protein feed, which can bring indirect climate and environmental benefits.[3] The relationship between increased bioenergy demand and indirect land use change is complex and difficult to attribute to just one factor. It should instead be assessed based on each country's unique circumstances. The EU Renewable Energy Directive (Directive 2018/2001) classifies agricultural feedstocks according to the risk of indirect land use change, with the aim of phasing out high-risk crops by 2030.

By focusing on bioenergy use on by-products and residues, i.e. parts of the bio-based feedstock that are already harvested but not used or cannot be used effectively, together with energy crops from unused land, the risk of undesirable land use change decreases. One example is using branches, tops, bark, sawdust or lignin, which are residues of trees that are felled to become sawn wood products, paper products or textiles. Other examples include using by-products from agriculture, where the energy in e.g. cereals and rapeseed are extracted before the nutrients are used for food and feed, or other biomass from farmland that is not used for food and feed production.

### Carbon sequestration in a systems perspective

An important prerequisite for bio-based feedstock to be considered sustainable is that it comes from a system where forestry and agricultural removal does not exceed growth, but carbon sequestering instead increases over time. Carbon dioxide is absorbed from the atmosphere over the lifetime of the plants. The carbon dioxide is regenerated when the plant dies and decays, or (if used as bioenergy) when it is burned. New carbon dioxide is absorbed when the plant is replaced with new plants which then grow in the same soil. From a cyclical perspective, this means that there is no net addition of carbon dioxide from the feedstock itself if replanting takes place.

Biogenic carbon dioxide is thus fundamentally different from carbon dioxide from fossil sources, where the carbon has been underground for millions of years and provides a net increase in carbon dioxide to the natural cycle when burned. This means that burning more fossil fuels will result in a need to sequester more carbon in the ecosystem. So, although the molecules are similar, biogenic and fossil carbon dioxide are not equal when it comes to their impact on the climate. Swedish forest legislation and the EU's sustainability criteria for bioenergy contain absolute requirements for regeneration. However, it is important that the forest and agricultural sectors continue to phase out the use of fossil fuels to minimise the climate impact of the use itself.

There are also so-called organogenic soils, i.e. peat and wetland soils, that give rise to significant greenhouse gas emissions when cultivated or trenched. The most effective way to reduce emissions from these soils is to restore them to wetlands.

For forest bio-based feedstock, harvesting cycles are long (up to a hundred years), and it takes a long time for a new tree to grow up in the same place. But it is misleading to count on the re-sequestration time of an individual tree or forest when the forest as a whole sequesters carbon through photosynthesis. The reasonable system boundary for carbon sequestration is Swedish agriculture and forestry as a whole, i.e. the entire area over which Sweden has jurisdiction and is accountable to the UN.

Emissions and uptake of biogenic carbon dioxide are reported under the EU LULUCF Regulation (2018/841) on land use, land use change and forestry and regulated together with the UN Framework Convention on Climate Change. Reporting includes changes in carbon stocks in living and dead biomass as well as soil carbon. Harvested biomass and its use for products with different lifetimes are also reported. This means that carbon stocks in, for example, wooden houses are included in the carbon stock, while feedstock that is burned, such as bark from pulp mills and branches and tops, is recorded as going directly to the atmosphere.[4]

Overall, this gives a holistic picture of carbon flows and carbon stocks and hence the climate impact of biogenic carbon dioxide, even if these are not reported together with other energy sources. The national estimates are the basis for international climate negotiations and for calling countries to account if the Paris Agreement is not met.

The LULUCF Regulation also requires that biomass removal in the EU is balanced by at least as much uptake of carbon dioxide from the atmosphere through growth, i.e. that carbon stocks in soil and vegetation do not decrease and that uptake exceeds removal so that carbon stocks are constantly increasing. In Sweden, uptake exceeds removal by 35–40 million tonnes of carbon per year.

The LULUCF Regulation is currently being revised and a proposal from the Commission proposes an increase of Swedish uptake to 47 million tonnes annually from 2030. Statistics clearly show that carbon stocks in the Swedish landscape have been increasing continuously for a long time and contribute to a sequestration equivalent to 60–70 percent of Sweden's terrestrial emissions.[5]

### Sustainable bio-based feedstock takes environmental objectives into account

How agriculture and forestry are conducted affects the possibility of achieving most of the Swedish environmental quality objectives, such as the objectives of living forests, fresh air, rich plant and animal life, no eutrophication and a rich agricultural landscape.[6] This means, among other things, that sustainability assessments and sustainability criteria are a key issue in the supply of bio-based feedstock for a transition to a sustainable, fossil-free society.

The EU Renewable Energy Directive (Directive 2018/2001) aims to promote the sustainable use of renewable energy sources, including bioenergy, and includes sustainability criteria for solid, liquid and gaseous biofuels.

A premise of this bio-strategy is that the supply of bio-based feedstock should always be within the scope of meeting set requirements and environmental quality objectives. In addition to the environmental benefits, this also increases the value of the bio-based feedstock and their international acceptance. For example, land that is valuable for biodiversity conservation needs to be set aside from use or developed in a way that safeguards biodiversity, based on a holistic approach at the landscape level. Loss and fragmentation of habitats is a major threat to biodiversity that must be actively countered if sustainable agriculture and forestry are to be achieved. When removing branches and tops, it is important to also leave a certain amount of dead wood and to return ash in order to minimise the impact of removal on the long-term productive capacity of the forest land and on biodiversity.

In some cases, biodiversity can also benefit from the removal of bio-based feedstock, for example by removing brushwood in agricultural landscapes and roadside verges. Reduced nutrient leakage can also be achieved by growing grasses and catch crops whose biomass can then be used for e.g. biogas production. Leys can also lead to increased carbon sequestration in the soil.[7, 8]

## 1.4 Delimitations and assumptions

In this strategy, Fossil Free Sweden has chosen a "conservative" approach and tried to solve the challenges of the roadmaps by starting from current levels of some important environmental factors that may affect the outcome of the potential and the sectors' needs for bio-based feedstock. These include, for example, forest harvesting levels, agricultural land area and waste incineration levels. Through this approach, the strategy can demonstrate that the bio-puzzle from the roadmaps can be resolved without dramatic changes compared to today. However, the strategy does not aim to resolve all other forest-related issues, nor does it take a position on these issues.

### Focus on by-products, residues and energy crops from agricultural land

Bio-based feedstock from forestry and agriculture are currently largely used in traditional applications to produce e.g. wood products, paper products, food and feed.

This strategy addresses the availability and use of bio-based feedstock mainly outside these areas, focusing on what is often referred to as bioenergy. However, bioenergy is a somewhat misleading term, as there are several important uses where bio-based feedstock is not primarily used for energy content but rather as e.g. feedstock for bio-based plastic.

Sawlogs, pulpwood, animal feed crops and food crops are not included in the supply and demand estimates given, with the exception of the current use of wheat and rapeseed for biofuel production. In the case of agriculture, pure energy crops such as energy forest are also included. However, there is a very strong dependence on the traditional forestry and agricultural value chains, as they will continue to be the economic drivers of forestry and agriculture. Naturally, the quantities of by-products depend on the production level.

Household and commercial waste, containing both biogenic and fossil fractions, are used as fuel in combined heat and power (CHP) plants. A large part of biogenic household waste and other biowaste is or can also be used for biogas production. This strategy does not explicitly address waste as a feedstock, but it is included implicitly through the impact on the need for other bio-based feedstocks.

### Assumption of forest harvesting at similar levels as today in relation to growth

It is difficult to assess future harvesting and production levels in the forest industry. There are many analysts who believe that there is room for an increase in stemwood removal due to the expected growth.[9, 10] At the same time, there are several actors in society who instead highlight the need to set aside a larger share of forest land for ecological purposes as part of the environmental objectives, and to move towards other forms of forest management, such as continuous forestry.[11, 12]

In terms of bio-based feedstock availability, the bio-strategy assumes that forest harvesting is at a similar level as in recent years in relation to the growth of productive land. This means the forests will continue to increase their carbon stocks and act as a carbon sink. At the same time, if forest growth increases as expected, mainly due to climate change, the harvesting levels may increase and more resources can thereby be used to replace fossil energy.

The strategy also assumes that the traditional forest industry's production of sawn timber and pulp will continue to be the economic driver of harvesting, and that this will be distributed in much the same way as today, even if the product mix changes, for example with a greater proportion of packaging at the expense of printing paper.

The strategy does not aim to determine how high future harvests can be or how forestry should be managed to achieve the environmental objectives set, but rather makes the assumption in order to show that the industry roadmaps can be implemented without major changes compared to today.

### No large-scale abandonment of agricultural land

In agriculture, the amount of land available, together with the availability of food production residues, is an important factor in the potential for increased production of feedstocks for bioenergy.

Since 1990, actively used arable land has decreased by about 10 percent. In addition, it is estimated that a further 10 percent is surplus leys that are not needed for feed production due to a reduction in livestock. More-over, the amount of fallow land that could be used for energy crops amounts to about 5 percent.[7]

There are projections that indicate that the abandonment of agricultural land will continue. At the same time, the increase in organic farming and increased focus on domestically produced food are trends that indicate a move in the opposite direction, i.e. increased need for cultivated land. A small proportion of agricultural land also consists of organogenic soils, drained peat and wetlands with high topsoil levels, which produce high greenhouse gas emissions and may therefore be considered for restoration to wetlands. This strategy's estimation of the availability of bio-based feedstock from agricultural land is based on the assumption that the area used for energy, food and feed production will be about the same in 2030 and 2045 as it is today.

As for forestry above, this is a conservative assumption regarding the potential for bio-based feedstock, as it implies that additional land for growing energy crops is not cultivated.

### Independence from net imports of bio-based feedstock

Sweden's ambition is to be a pioneering country in climate change mitigation, and the design of policy instruments and the technological development that takes place here should therefore also help to accelerate the transition in other countries. In a changing world, the demand for bio-based feedstock is expected to increase, which also means there is an increased risk of losing biodiversity and other negative environmental impact. Here, Sweden has a unique role to play in using its favourable situation, as relates to the availability of bio-based feedstock, in a global perspective. Although electrification and hydrogen have great potential as enablers of climate change mitigation, there are sectors where electrification is not possible and where long-term sustainable bio-based feedstocks from Sweden can contribute to enabling the transition even globally. The strategy work has therefore been based on the assumption that Sweden will be a net exporter of bio-based products for energy purposes and industrial use outside the traditional forest industry and agriculture by 2045. This does not exclude imports of feedstocks or products. These will be traded internationally, as different types of bio-based feedstocks have different characteristics and applications.

### Carbon capture may influence the future use of bio-based feedstock

Carbon capture and storage (CCS) technologies are a complement to reduce parts of industry's fossil carbon dioxide emissions that are very expensive or technically difficult to manage by other means with current technologies. CCS is also an important opportunity to reduce fossil carbon dioxide emissions in the shorter term, before the transition to new fossil-free technologies takes place.

As this strategy deals with the use of bio-based feedstock for a fossil-free transition of society, fossil CCS is outside of its direct focus. However, it is important to point out that the implementation of CCS, where and when it takes place, will have an indirect impact on how bio-based feedstock is used in the transition.

In contrast, bio-CCS, i.e. the capture and storage of biogenic carbon dioxide, is directly linked to the use of bio-based feedstock and can have an impact on its use in different sectors.

Carbon capture and utilisation (CCU), where the carbon dioxide captured is used as a feedstock in materials and products, can also have an impact on the use of bio-based feedstock.

### Conversion to primary energy

Many sources do not distinguish between different types of biofuels/bio-based feedstocks when tallying up bio-based feedstock requirements, which means that the sums include everything from biogas and liquid fuels to bark and harvesting residues. An estimation of primary energy demand has therefore been carried out, so that figures for bioenergy use and need represent primary energy (mostly unprocessed biomass).

Where this information is not available from the source, a rough estimate of an average 70 percent efficiency from primary energy to liquid or gaseous fuels has been used, based on efficient biorefinery concepts. The actual efficiency will of course vary greatly depending on the choice of feedstock and conversion process, but 70 percent is considered realistic to achieve on average in the longer term for the main alternatives available. Depending on technology choice and development, this could be both higher and lower. Note that this efficiency refers to that between processed product and unprocessed feedstock, but energy inputs in other forms may also be required, usually electricity. In addition, waste heat can in many cases be recovered, especially for process alternatives with lower efficiency levels. In cases where unprocessed bio-based feedstock can be used, such as incineration in combined heat and power plants, no adjustment is made.

The estimate of demand is thus comparable to the estimates of potential made and discussed in this strategy. As losses always occur when bio-based feedstock is converted to a more refined form, such as fuel, the needs reported are sometimes higher than those found in the sources, which often do not take into account the degree of refinement.

# 2. How is bio-based feedstock currently used in Sweden?

Sweden's total bioenergy use is approximately 140 TWh/year (Figure 1). More than 100 TWh of this comes from forests, of which more than half is used for the forest industry's own energy consumption. Approximately 20 TWh are biofuels, most of which are imported, and approximately 20 TWh come from household waste, agriculture, etc. Thus, of the current domestic supply of bioenergy, about 85 percent is forest-based.

The total bioenergy use shown in Figure 2 is almost 160 TWh/year, converted to primary energy; see Chapter 1.3. The use is mainly in industry, which is mostly the forest industry and electricity/district heating, but also some other heating. The use of bioenergy for electricity in Figure 2 (18 TWh/year) includes electricity production in both industry and district heating. The amount of energy for district heating (38 TWh/year) also includes the biogenic fraction of various waste streams.

The amount of bio-based energy in the transport sector has increased significantly over the last ten years, mainly through imports. It is important to note that net import relates to feedstock for bioenergy, not biomass in general and bio-based products, where Sweden is a net exporter.

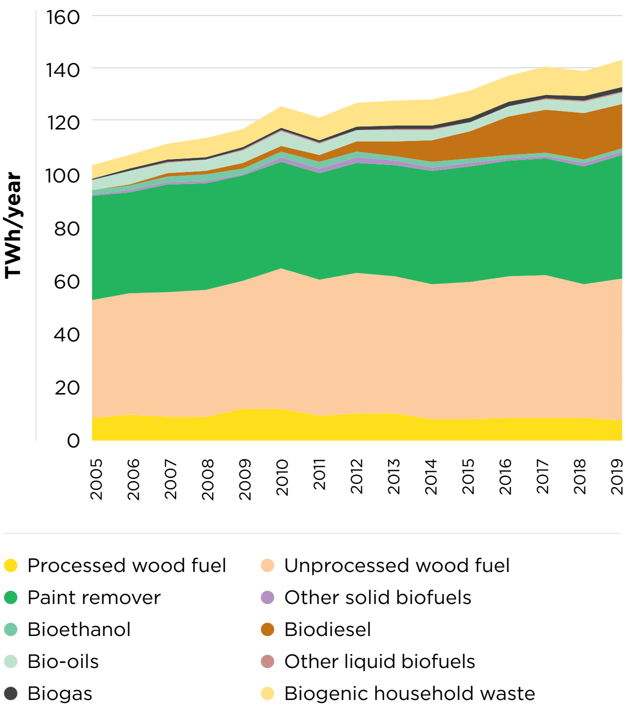



**Figure 1:** Bioenergy use in Sweden 2005–2019.

**Source:** Swedish Energy Agency (2021) Energy in Sweden Facts and Figures.[13]

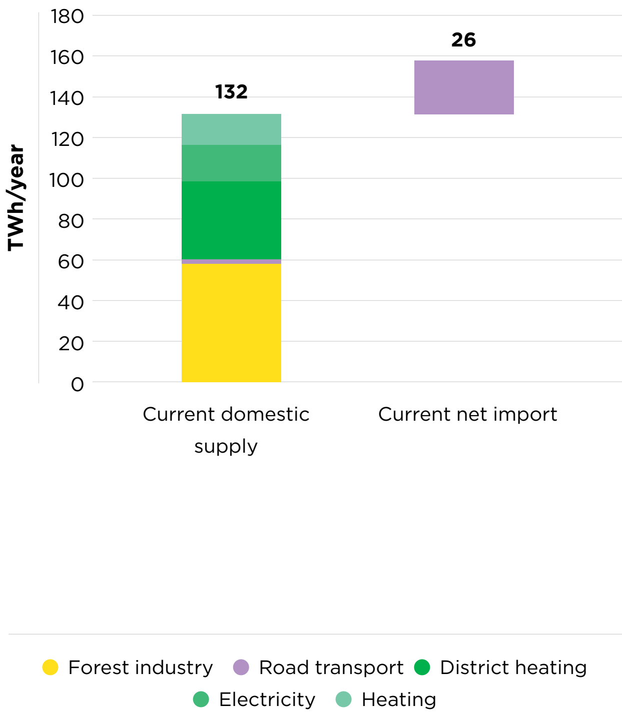



**Figure 2:** Bioenergy use in Sweden, converted to primary energy.

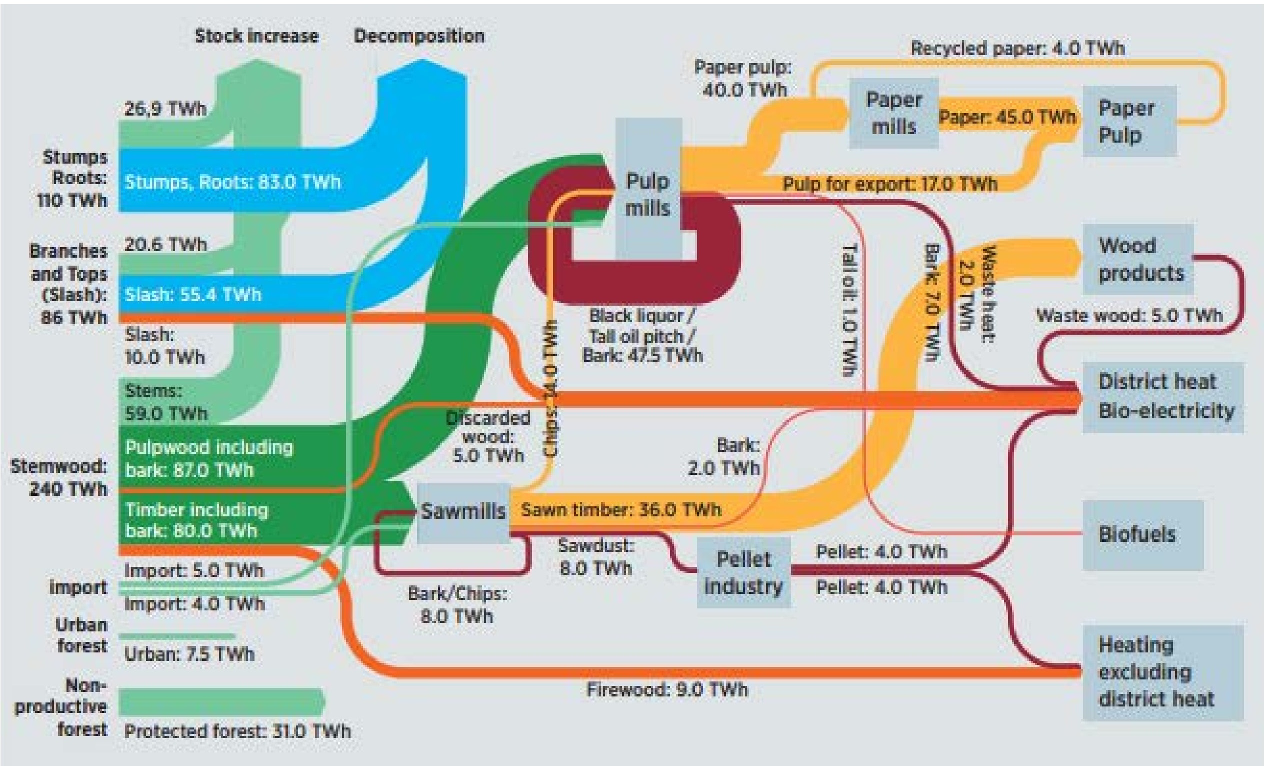
## 2.1 Bio-based feedstock from forests

Sweden currently has about 23 million hectares of productive forest land, with a timber stock of 3.3 billion cubic metres, equivalent to 12,000 TWh. Annual growth is about 120 million cubic metres, or just over 400 TWh. About 20 million hectares are under cultivation and about 75 percent of the growth was harvested in 2015 (Figure 3).[7, 9]

Energy flows in the forest sector are illustrated in Figure 3, which also includes the growth and use of pulpwood and sawlogs. It clearly shows the interdependence between the supply of residues and by-products and the traditional forest industry, which produces sawn wood products, pulp and paper. Forestry today is economically driven entirely by the production of sawn wood products, pulp and paper. About half of the stemwood that goes to sawmills and pulp mills becomes pulp and sawn timber. The other half, approximately 75 TWh/year, becomes by-products and residues used for energy purposes, mainly black liquor, pitch oil, bark, sawdust and wood chips.

In addition to stemwood, the residual products branches and tops are produced during forest harvesting. Although branches and tops have potential as a bioenergy feedstock, they have a much lower value than stemwood due to factors such as high transport costs. They are therefore currently taken out and only used to a limited extent.

Most of the residues and by-products from sawmills and pulp and paper mills are used internally for their own energy supply, but about 20 TWh/year is used outside




- Harvested timber
- Unharvested growth remaining in the forest
- Branches, tops and stumps left in the forest after harvesting
- PProduct flows, incl. recycling
- Primary bioenergy (directly from the forest)
- Secondary bioenergy (forest industry residues)

**Figure 3:** Annual energy flows in the Swedish forest sector, 2015.

**Source:** Svebio (2020), "Färdplan Bioenergi – så möter vi behovet av bioenergi för fossilfritt Sverige" [Bioenergy roadmap – How to meet the bioenergy need for fossil-free Sweden].[10, 14]

of the forest industry, almost exclusively for production of electricity and heat. Residues and by-products that come directly from forestry are also used mainly for electricity and heat, and consist of about 10 TWh/year of branches and tops, about 5 TWh/year of damaged wood, and about 10 TWh/year of firewood. The latter is used directly for small-scale heating.

Most of the biofuel production that takes place in Sweden today from forest feedstock is based on tall oil formed during pulp production. The production of tall oil currently amounts to 1 TWh/year. This, together with a small production of methanol at Mönsterås pulp mill and ethanol at Domsjö Fabriker, is the only forest-based biofuel production currently taking place in Sweden.

## 2.2 Bio-based feedstock from agriculture

The production of crop products (mainly for food and feed) in the agricultural sector amounts to 53 TWh/year, of which 25 TWh are cereals, 21 TWh are grasses, 2 TWh are oilseeds and the rest are mainly sugar beet, potatoes and legumes. At the same time, approx. 21 TWh/year of residues are produced in the form of stalks and haulm. Grain stalks account for the largest share, approximately 16 TWh/year.[7]

The energy-related use of agricultural production of crop products is mainly fuel production:

- Ethanol is produced from wheat at the Lantmännen Agroetanol plant in Norrköping. This has the capacity to use approximately 2.5 TWh/year. The proportion of domestic feedstock varies, but overall Sweden is a net exporter of wheat. A significant proportion of ethanol production has historically been exported.
- Domestically grown rapeseed is used for the production of biodisel (RME). The total domestic production capacity is 1.5–2 TWh/year. This is currently supplied by a mix of domestic and imported rapeseed oil.

The main feedstocks for biogas production are residues and wastes, mainly sludge from wastewater treatment, manure, food waste and waste from food production.[15] Biogas production in Sweden is currently about 2.1 TWh/year, of which about two-thirds is upgraded to vehicle gas quality. Total biogas use amounts to about 4 TWh, of which about half is imported.

As for the residues stalks and haulm, only a very limited proportion is currently used for biogas production and energy production. Approximately 4 percent of Swedish arable land is used for biofuel production.[16] The cultivation of energy forest is marginal today, and it is used as fuel for heat production.

# 3. Demand for bio-based feedstock in a fossil-free Sweden 2045

To achieve the climate target of zero net greenhouse gas emissions by 2045, there must be a total system transformation, with major changes in many sectors that currently use fossil feedstocks. The transition is expected to lead to a significant increase in the demand for bio-based feedstock, as this is currently a cost-effective solution in many industries. This chapter aims to provide a summary of what that demand looks like.

Roadmaps for fossil free competitiveness[17] provide a picture of the need for bio-based feedstock for the transition in different industries and sectors. However, in many cases the picture in the roadmaps is only qualitative. Quantitative compilations of electricity and biofuel needs in the roadmaps were carried out by Sweco in 2019 on behalf of the Confederation of Swedish Enterprise[18] and in the Royal Swedish Academy of Engine-

| | | Bioenergy 2030 | | Bioenergy 2045 | |
|---|---|---|---|---|---|
| | | **Primary energy** | **Use form** | **Primary energy** | **Use form** |
| Industry | Steel | 3-6 | 2,5-4 | 7-9 | 4-6,5 |
| | Mining and minerals | 3-4 | 2-3 | 3-4 | 2-3 |
| | Cement | 2-3 | 2-3 | 4-5 | 4-5 |
| | Chemicals A | 1,5-2,5 | 1-2 | 0-25 | 0-13 |
| | Metal | 0 | 0 | 1-2 | 1-2 |
| | Forest B | 2-3 | 2-3 | 2-3 | 2-3 |
| | **Subtotal** | **12-19** | **10-15** | **17-48** | **14-33** |
| Transport | Road | 20 | 14 | 20 | 14 |
| | Domestic aviation and maritime transport | 3 | 2 | 4,5-6 | 3-4 |
| | Machinery | 7-10 | 5-7 | 8,5-9 | 6-6,5 |
| | **Subtotal** | **30-33** | **21-23** | **33-35** | **23-25** |
| Electricity/heating | District heating C | 0 | 0 | 0 | 0 |
| | Electricity C | 0 | 0 | 0 | 0 |
| | Heating C | 0 | 0 | 0 | 0 |
| | **Subtotal** | **0** | **0** | **0** | **0** |
| | **Total** | **42-52** | **31-38** | **50-83** | **37-58** |

**Table 1** Compilation of projections for increased bioenergy and bio-based feedstock needs for transition by 2030 and 2045, based on Roadmaps for fossil free competitiveness, Sweco and the IVA.[23, 28, 22] Primary energy needs in bio-based feedstock are estimated. All values in TWh/year.

**A** The chemical industry has not drawn up a roadmap within the framework of Fossil Free Sweden. The estimate is instead based on the IVA's data (see text).
**B** Relates to the phase-out of fossil fuels used and some additional energy requirements for bio-CCS. Sawlogs and pulpwood are not included.
**C** Some additional energy requirement for bio-CCS in the district heating sector. The roadmaps for the electricity and heating sectors do not include any quantification of increased need for bio-based feedstock.

ering Sciences' (IVA) work in the project "Vägval för klimatet" [Choices for the climate].[19, 20, 21, 22]

Sweco's analysis of the roadmaps is based on the first nine of the roadmaps. Where necessary, dialogues have been held with industry representatives to quantify the need. The transport sector, which plays an important role in several roadmaps, has been singled out and handled separately. The same applies to machinery, which is handled together with the transport sector.

The compilation shown in Table 1 is limited to the use of bio-based feedstock to reduce territorial emissions. It should be noted the fuel needs for international transport bunkered in Sweden are significant, approximately 10 TWh/year for aviation (excluding the effects of the pandemic) and approximately 24 TWh/year for maritime transport.

Figure 4 shows the current use of bio-based feedstock together with the estimated need for 2030 and 2045 based on data from the roadmaps, Sweco and the IVA. The maximum need has been calculated as 211 TWh for 2030 and 241 TWh for 2045. In its report "Klimatagenda för Sverige" [Climate agenda for Sweden], Material Economics made a similar estimate of the need for bio-based feedstock for 2045 based inter alia on the industries' roadmaps, and came to a similar conclusion of a potential future demand of about 250 TWh.[24]

## 3.1 Industry sector

The needs of bio-based feedstock for industry transition in 2045 is largely based on the roadmaps and Sweco's analysis of these. With the addition of the new plant that H2 Green Steel plans to erect in Boden (which was not known at the time the roadmap was created), need within the steel industry will be 7–9 TWh/year in 2045 if the same assumptions on the use of bio-based feedstock for biochar and heating are made for this plant as for similar production in the roadmap. Both the mining and minerals industry and the cement industry will have a high demand for biofuels for heating. According to Sweco's analysis, the need is 2–3 TWh/year and 4–5 TWh/year, respectively. The forest industry needs 2–3 TWh/year of fuel to phase out the last fossil fuels.

Potentially the largest volumes of bio-based feedstock

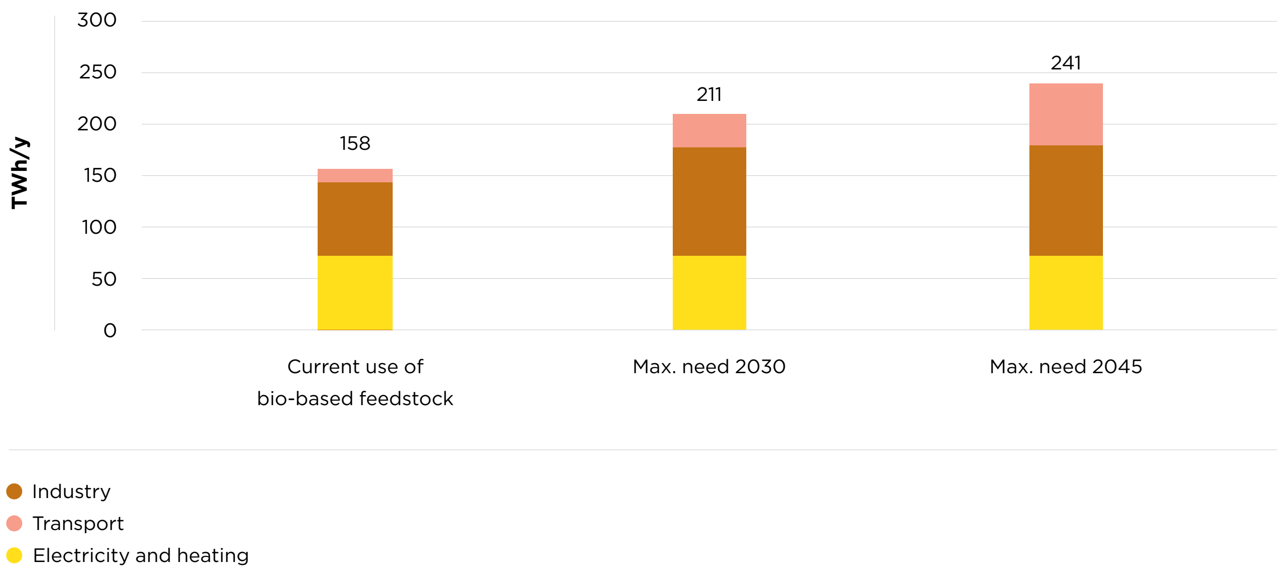



**Figure 4:** Current use of bio-based feedstock compared to need estimated based on data from Roadmaps for fossil free competitiveness, Sweco and the IVA17,[18, 22] for 2030 and 2045, reported as primary energy. The maximum need is used from intervals in Table 1.

in the industry sector may be required in the chemical industry – but this is also where the greatest uncertainties exist. The chemical industry has not made a roadmap within the framework of Fossil Free Sweden, so the estimate for 2045 is instead based on an assessment by the IVA.[19] It indicates that the chemical industry can make different choices that result in completely different needs for bio-based feedstock, from zero to 13 TWh/year of processed feedstock (biomethanol and biogas).

According to the IVA, up to 25 TWh/year of bio-based feedstock could be required for this. For 2030, it is assumed that only 1–2 TWh/year of biogas will replace natural gas.

## 3.2 Transport sector

The analysis of the transport sector and the fuel needs in the Sweco report is not directly based on the underlying roadmaps for fossil freedom, as the roadmaps are often not quantitative in terms of transport, have large overlaps between each other, and scenarios for the transport sector as a whole require assumptions beyond what is included in the individual roadmaps. At the time of the Sweco report, there were no roadmaps from the automotive industry, maritime industry, petroleum and biofuel industry, and the gas sector. Sweco's analysis of the road transport sector is instead based on the FFF study [fossil-free vehicle fleet study] from 2013.[25]

The total demand for gaseous or liquid fuels for road transport, machinery, domestic aviation and domestic maritime transport is estimated at around 44 TWh/year in 2045. Of this, around 34 TWh/year is liquid fuel for road transport, compared to around 20 TWh/year today. The level of passenger car electrification assumed by Sweco is lower than indicated by the automotive industry's roadmaps for heavy-duty vehicles and passenger cars. The Sweco compilation's estimated need of fuel for machinery is 6 TWh/year. This estimate is based on assumptions of electrification equivalent to 15 percent of the energy need today, and 35 percent efficiency improvement.

Sweco's analysis of domestic fuel demand for 2030 is based on the Swedish Energy Agency's reduction obligation scenarios from 2019,[26] which is about 40 TWh/year for road transport in 2030. In the petroleum and biofuel industry's roadmap, the industry points out that scenarios with a higher proportion of biofuel may have lower overall costs compared to scenarios with a higher degree of electrification. The industry states that member companies have a total production ambition of more than 100 TWh/year, but does not make a distinction between Swedish and foreign production growth or between use in a domestic and international market.

## 3.3 Electricity and heating sectors

Today's Swedish electricity system is characterised by large shares of hydropower and nuclear power, wind power under rapid expansion, and biofuel and waste-based CHP production. When it comes specifically to the demand for bioenergy, the electricity and heating systems must be analysed together, as at present there is virtually no bio-based electricity production that does not also produce heat. For reasons of efficiency and cost, this is not likely to change in the future.

Both the heating and the electricity sectors have created roadmaps. The heating sector's vision is to be fossil fuel free by 2030 and a carbon sink by 2045. The sector points to increased use of various types of residual heat and, in addition to CHP-based district heating production, for high overall efficiency and to help reduce the power challenge of the electricity system. The sector argues that a significant reduction in the use of biofuels in the heating sector could jeopardise the transition of the energy system, but does not predict a significant increase either. för en hög totaleffektivitet och för att bidra till att minska elsystemets effektutmaning. Branschen menar att en avsevärt minskad användning av biobränslen i värmesektorn kan äventyra omställningen av energisystemet men prognosticerar heller inte någon omfattande ökning.

# 4. Availability of bio-based feedstock

Like many other inputs, the availability of bio-based feedstock is physically limited. However, within the physical constraints, the sustainable potential of bio-based feedstock is determined by a number of economic and environmental assessments, trade-offs and assumptions. This chapter briefly describes a resulting estimate of a sustainable amount of bio-based feedstock that could be used in the transition, given the environmental considerations and the forest industry production levels discussed in Chapter 1. The estimate is based primarily on the report "Potential för ökad tillförsel och avsättning

A summary of the increased availability of bio-based feedstocks, compared to the current situation, is given in Table 2. In addition to today's use, it is estimated that there will be an additional bio-based feedstock supply of about 40 TWh per year in 2030. In 2045, the corresponding figure will be about 53 TWh/year.

## 4.1 Forestry by-products and residues

Forestry by-products and residues consist primarily of branches and tops, which are the parts of the tree that (together with stumps and roots) are not considered

| | 2030 | 2045 |
|---|---|---|
| **Forest** | | |
| Branches and tops | 16–18 | 18–21 |
| Damaged roundwood | 3–4 | 3–4 |
| Thin roundwood (clearings, etc.) | 2–3 | 3–4 |
| Subtotal | 21–25 | 24–29 |
| | | |
| **Agriculture** | | |
| Stalks | 2–4 | 2–4 |
| Biogas residues | 4-6 A | 4-6 A |
| Woodland B | 3–4 | 5–7 |
| Energy forest on abandoned land | | 2–6 |
| *Subtotal* | *9–14* | *13–23* |
| | | |
| **Brushwood** | 5–8 | 8–10 |
| | | |
| **Total** | **40 (35–47)** | **53 (45–62)** |

**Table 2** Estimated increased potential for feedstocks from bio-based feedstock from forestry and agriculture. All values in TWh/year.

**Source:** Börjesson, P. (2021), "Potential för ökad tillförsel av inhemsk biomassa i en växande svensk bioekonomi – en uppdatering" [Potential increased supply of domestic biomass in a growing Swedish bioeconomy – An update],[27] but with adjustments for other assumptions about harvesting levels; see Chapter 1.4.

**A** For these items, the potential for biogas production is given rather than the feedstock energy, as the efficiencies of the conversion are so different. Re sidues refers to e.g. manure.
**B** From woodland, grass is probably the most important feedstock that is not currently used.

stemwood. Branches and tops can also be collected during thinning.

The limits for what constitutes ecologically sustainable branch and top removal are set primarily by the environmental objectives of Sustainable Forests, A Rich Diversity of Plant and Animal Life, and Natural Acidification Only.[28] Bark from sawmills and paper mills and sawdust from sawmills are also by-products and residues addressed in the strategy.

According to Börjesson[27] and de Jong et al.[28], it is possible to increase the removal of branches and tops by 16–18 TWh/year compared to the current level without impacting other environmental objectives. This additional potential implies a removal of 70 percent of the branches and tops resulting from harvesting from about 50 percent of the harvested areas suitable for this purpose. The potential for increased branch and top removal varies between different parts of the country. A larger proportion is currently removed in southern Sweden than in northern Sweden due to greater demand, which in turn leads to lower costs. By 2045, the potential is somewhat greater due to the increased growth expected.[9, 27]

Stumps are not included in the potential for bio-based feedstock presented here. Stump grinding entails risks of negative ecological consequences, and is not approved under the certification used in forestry today. It is therefore concluded that stump harvesting will not occur to any significant extent.

Damaged and infested roundwood cannot be used for timber or pulp, but can be used as biofuel. The amount of insect infestation in Swedish forests is expected to increase with global warming. A reasonable assumption is that the amount of damaged roundwood that thereby becomes available for bioenergy production can be expected to increase by an additional 3–4 TWh/year from today's approximately 5 TWh/year.

## 4.2 Agricultural crops and by-products

The potential for increased use of bio-based feedstock from agriculture consists of both better use of residues from food production and increased production on abandoned arable land. As by-products cannot be used as food or feed, they are not limited by the "cap" on crop-based feedstocks in the EU's Renewable Energy Directive (Directive 2018/2001). This strategy's estimation of the availability of bio-based feedstock from agricultural land is based on the assumption that the area used for food and feed production will be about the same in 2030 and 2045 as it is today, as discussed in Chapter 1.4.

Börjesson[27] estimates the future availability of stalks for bioenergy as 2–4 TWh/year. This is a relatively modest share of the total production of grain stalks, which amounts to 16 TWh/year, and the limitation is made for practical, environmental and economic reasons.

Börjesson estimates the potential increase in biogas production from other residues, such as manure, food waste, haulm and sludge, as 4–6 TWh/year for 2030 (for feedstocks that have no reasonable use other than biogas production through anaerobic digestion, the amount is given as biogas potential rather than energy in feedstock). This estimate fits well with the 2030 target of the biogas study.[29]

In addition, there is a surplus of grasses, which can be used as feedstock for biogas or other types of bioenergy, mainly from woodland. Börjesson[27] estimates this potential as 3–4 TWh/year today and 5–7 TWh/year in 2050, with this potential being used for 2045 in this strategy. As discussed above, this strategy does not make any major assumptions about land use change in the longer term. The increase between 2030 and 2050 is mainly due to improved and adapted harvesting systems.

There are currently about 100,000 hectares of abandoned arable land and about the same amount of abandoned pasture land.[7] The latter may have high ecological values, but it would be advantageous to use the abandoned arable land to grow so-called energy forests (e.g. poplar or hybrid aspen), with a potential of 2–6 TWh/year. As the number of such plantations is marginal today, and the production cycle for a tree generation takes 20–30 years, the potential is from 2040 and onwards. As no large-scale abandonment of agricultural land is assumed, the area available for energy forest cultivation is today's abandoned land.

## 4.3 Brushwood

Brushwood refers to young trees and bushes, often deciduous, found e.g. along roads, in power lanes, along the edges of fields, and in overgrown pastures. There are large amounts of overgrown land, and harvesting brushwood often has a positive effect on biodiversity.[28,30] The potential of brushwood harvesting is estimated at 5–8 TWh/year, based on a study by the Swedish University of Agricultural Sciences,[31] and 8–10 TWh/year in 2045 due to the development of harvesting technologies and the increased need to support biodiversity in the agricultural landscape.[27]

# 5. Technology and price development for bioenergy

The conditions for the production and use of bioenergy are changing due to both technological developments and external trends. These include what types of biofuels are used in the transport sector and how the price of bio-based feedstock is expected to develop in coming years. All this will affect the demand for bioenergy and its ability to compete with other solutions.

## 5.1 Near-term technology options for biofuel production

Most scenarios for road transport biofuel need indicate a higher need in 2030 than in 2045, mainly due to electrification as discussed in more detail in Chapter 7.1. The Swedish Transport Administration[32] estimates the 2030 need to be 70 percent higher than today's approximately 34 TWh/year, while several other projections instead land on a need of 30–50 TWh/year in 2030.[26] For aviation, the recently decided reduction obligation gives a demand of about 4 TWh/year in 2030.

The total biofuel production capacity in Sweden is currently about 5 TWh/year. Today's import need combined with the expected increase in demand within both road transport and aviation leads to several actors to plan for an increased domestic production capacity of biofuel.

In terms of volume, the predominant biofuels in Sweden today are HVO and biodiesel based on fats and oils as feedstock base. Almost all of the existing and planned investments for biofuel production in Sweden are also based on fats and oils rather than domestic residues from forestry and industry.

Examples of major existing plants are Preem's HVO production in Gothenburg (200 kt/year) and Adesso Bioproducts' biodiesel production in Stenungsund (150 kt/year).

Examples of planned plants are St1's in Gothenburg (200 kt/year) (under construction), Preem's in Gothenburg (1 Mt/year) and Preem's so-called SynSat project in Lysekil (650–950 kt/year). If all of the planned plants are built, altogether this will provide up to 30 TWh/year of the fat and oil-based fuels HVO, HEFA and biodiesel.

Sweden currently has little additional supply of oil and fat feedstocks that can be used in these plants, although there is some supply of used frying oil and slaughterhouse waste. By investing in and developing pre-treatment of e.g. lignin or liquefied lignocellulose, other types of feedstocks could also be used in the plants. But since the plants are designed for oils and fats, there is a risk, for technical and economic reasons, that this will only be done to a limited extent and that the feedstocks will therefore continue to have to be imported to a large extent.

Palm oil and PFAD, which is produced at the same time as palm oil, are currently important feedstocks for biofuel production. In a delegated act, the EU Renewable Energy Directive (Directive 2018/2001) classifies agriculture feedstocks according to risk of indirect land use change (ILUC risk). Feedstocks classified as high risk are to be phased out in the EU by 2030. Palm oil is currently classified as a high-risk feedstock, and, in Sweden and those Member States where PFAD is classified as a co-product, PFAD is also classified as high risk. In the agreed proposal of reduction obligations for petrol, diesel and aviation kerosene, palm oil and PFAD cannot be used in meeting these obligations from 2022, as these feedstocks are classified as high-risk feedstocks under the Renewable Energy Directive.[33]

At the same time, a sharp increase in global demand for biofuels is expected, for example as a result of the recently announced tightening of the EU's 2030 climate ambitions, which is expected to require 24 percent renewables in the transport sector compared to 8 percent today.[34] This is leading to a major ongoing and upcoming expansion of production capacity globally, particularly for HVO, and a subsequent sharp increase in international competition for bio-based feedstocks of the type oils and fats. This may also be a driver towards the use of feedstocks with a greater environmental impact.[21]

Sweden has good prospects for increased domestic production of renewable fuels, including biogas, from domestic residues from forestry, the forest industry and agricultural crops and by-products, which can also have other positive effects on society.[35] However, alternative biofuel production technologies, which can use feedstocks from the forest industry in particular, have so far not been competitive, largely due to high investment costs combined with the fact that the technologies are often not yet implemented on a commercial scale.

An ongoing assignment at the Swedish Energy Agency aims to investigate policy instruments to promote Swedish production of biofuels, including renewable gas, using new technologies. This could be a very important piece of the puzzle for realising the potential for biofuel production from sustainable feedstocks that are available in larger quantities in Sweden.[36]

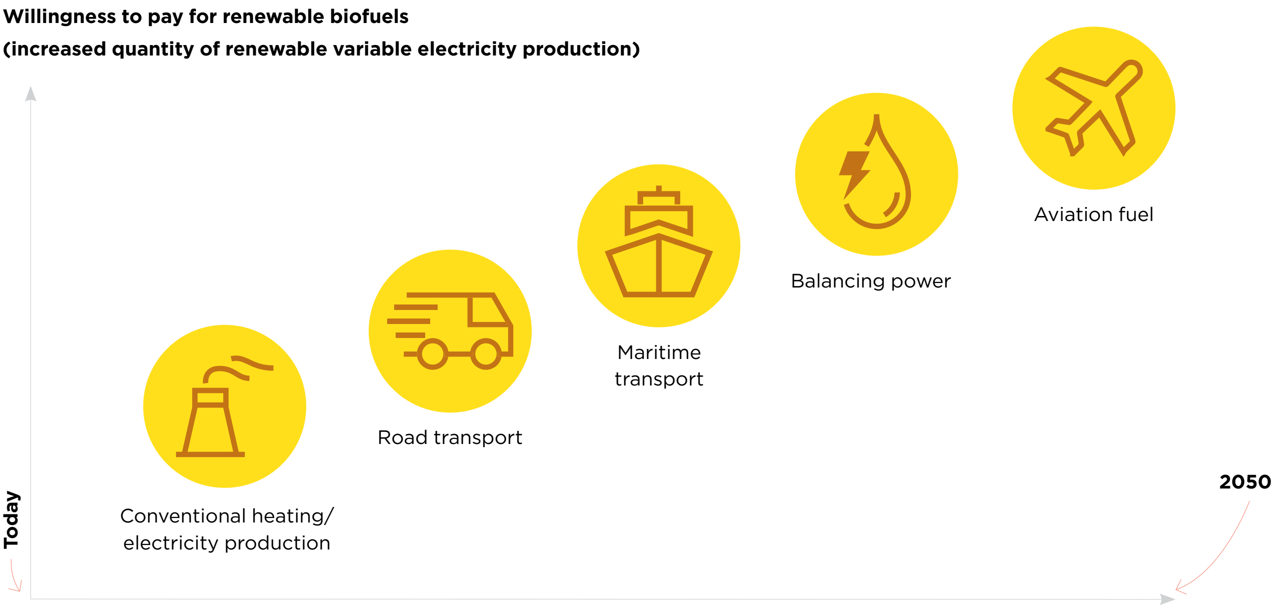
## 5.2 Cost trends for bio-based feedstock and electricity

This strategy takes a qualitative approach to the impact of electricity and bio-based feedstock prices on different areas of bio-based feedstock use, as a quantitative estimate of future prices is very difficult and uncertain.

### Bio-based feedstock

Increased demand for bio-based feedstock is likely to lead to higher prices as more countries align with the Paris Agreement. In the coming years, the highest willingness to pay for biofuels is likely to be in the road transport sector, while in the longer term it is likely to be highest in those sectors where other fossil-free alternatives are lacking; see Figure 5. Bio-CCS may also become an area of increasing willingness to pay for bio-based feedstock in the future, and will thus compete with other bio-based feedstock use.[37]

Price increases may also be due to increased removal and transport costs. For forestry residues, studies[38, 39]




**Figur 5:** Value diagram to illustrate the future use of bioenergy and how the willingness to pay might look over time. The need to reduce fossil carbon dioxide emissions will steer the use of bio-based feedstock to the sectors where there is the highest willingness to pay and it is difficult to replace fossil carbon sources with other alternatives.

**Source:** Kungl. Skogs- och Lantbruksakademiens tidskrift (2018), Forests and the climate. Manage for maximum wood production or leave the forest as a carbon sink?

suggest that the cost-supply curve for the removal of branches and tops is relatively flat.
However, increased removal will likely result in longer transport distances, leading to increase costs. However, increased demand for bio-based feedstock makes it more profitable to harvest/exploit available resources to a greater extent than today, despite increased transport costs.

For residues from sawmills and mills, there is no well-defined production cost. The market price instead varies with demand and transport distance.

Energy forests can be produced at a slightly higher cost compared to the collection of forestry residues, and a switch to such feedstock only involves a minor change in feedstock costs.[40]

### Electricity

Investments in new fossil-free production technology will mean a sharp increase in Swedish electricity consumption in 20–25 years' time. Both industry and politicians have pointed to a forecast of a doubling from today's 130 TWh by 2045. The major transformation of industry, the transport system, and the energy sector will place great demands on the development of the energy system. To succeed in the transition to fossil freedom, the development needs to be both rapid and far-reaching, requiring major investments in both electricity production and distribution, as well as faster and more predictable permitting processes. Solar energy costs have fallen sharply in recent years, and it is now the cheapest way of generating electricity globally. Wind power, which often generates most of its electricity at night and in the winter when the sun is not shining, has also had a very favourable cost trend, with costs almost halved over the last decade.

The rate of expansion of renewable electricity production in Sweden is high. Wind power production increased from 20 TWh in 2019 to 28 TWh in 2020, representing a 40 percent expansion of total production in one year. The same rate of development is expected to continue in the coming years, and the Swedish Energy Agency's main scenario is 80–120 TWh of renewable electricity production in 2045.

With a large proportion of weather-dependent renewable electricity production, solutions to balance the system will be important, as will the costs of these.
Electricity storage will be an important solution. Both batteries and chemical storage, where electricity is used together with e.g. carbon dioxide to produce electrofuel or hydrogen, will be important in different ways depending on the need for the time interval of storage. Both technologies currently have high costs for large-scale storage, but costs are now falling rapidly. Other technical solutions will also be important, such as the use of wind power's own balancing capacity, demand flexibility, and the interaction with the heating system and future large-scale hydrogen storage.

How solutions based on direct or indirect electrification can compete with bio-based solutions will depend on factors such as the evolution of the cost of renewable electricity, electrolysers and storage facilities, and how the price will be affected by increased demand. The visions for and expansion rate of solutions for e.g. hydrogen are largely the result of expectations of low costs for renewable electricity, which will also determine the scale of the initiatives.

Swedish transmission system operator's long-term market analysis,[41] launched in May 2021, presents four scenarios with varying degrees of renewable electricity production, with three of the four scenarios showing continued low or falling annual average prices in the four electricity markets in 2045. In some scenarios, prices increase until 2035 and then decrease until 2045.

The scenarios assume different levels of growth in electricity use, making pure comparisons difficult. However, some important trends can be identified:

1. Electricity prices generally become more volatile and are even more linked to variations in production.
2. Renewable electricity production, such as offshore wind power, can contribute to a high proportion of hours with low electricity prices.
3. A low rate of expansion of renewable electricity production would lead to a weaker electrical energy balance in the Nordics and thereby a high proportion of high-price hours.
4. The average annual price varies greatly depending on both weather conditions and electricity prices in Europe.

# 6. Political conditions

There is a wide range of regulations that affect in different ways the use of bio-based feedstock for the type of applications addressed in this strategy, both at the EU and the national level. This chapter briefly discusses the most important of these regulations, and some ongoing processes that are considered to have a major impact on their future development and thus on the conclusions drawn in this bio-strategy.

## 6.1 EU

### The Green Deal

In June 2021, the Parliament decided to raise the level of ambition of the Union's climate target to 55 percent greenhouse gas reduction by 2030 compared to 1990. A major policy package ("Fit for 55") related to this new target was presented by the Commission in July 2021. The package aims to specify where emission reductions should take place, and includes proposals for maritime transport to become part of the Emissions Trading Scheme (ETS), a parallel trading scheme for emissions related to buildings and road transport, and also so-called climate border tariffs (CBAM) for trade flows that generate large greenhouse gas emissions, such as iron and steel, cement and electricity. The proposals included in the "Fit for 55" package will be negotiated with the Parliament and Member States in the coming years.

The EU already has a target of net zero greenhouse gas emissions by 2050. In addition, a number of strategies have been published as part of the European Green Deal, such as biodiversity strategies, the Farm to Fork Strategy, the Hydrogen Strategy, and the Sustainable and Smart Mobility Strategy. A forestry strategy has also been presented, which sets out guidelines for forestry in the EU. The strategy focuses on the conservation of biodiversity, the protection of valuable nature and climate, and states, for example, that clearcutting should be avoided. The EU forestry strategy thus has a potentially major impact on how Swedish forestry will be conducted in the future.

The two initiatives RefuelEU aviation and FuelEU maritime contain proposals for regulations that steer towards increased use of sustainable fuels in aviation and maritime transport. For aviation, a quota obligation for sustainable aviation fuel in the EU is proposed, starting at 2 percent in 2025, 5 percent in 2030 and 63 percent in 2050, with electrofuels accounting for 0.7 percent and 28 percent in 2030 and 2050, respectively. For the maritime industry, the suggested levels for renewable and low-carbon fuel are 6–9 percent for 2030 and 86–88 percent for 2050.

### Taxonomy

The so-called EU Taxonomy is part of the EU Green Deal and aims to define a classification system for sustainable economic activities to guide private capital towards the transition. The Taxonomy is expected to have a major impact on climate and sustainability work in the EU. Activities classified as green under the Taxonomy are likely to find it easier to attract capital, especially from investors focused on transition. In the final proposal from the Commission, bioenergy is classified as a sustainable solution if sustainability criteria linked to the Renewable Energy Directive (Directive 2018/2001) are met.

### Renewable Energy Directive

The Renewable Energy Directive (RED, Directive 2018/2001) aims to promote the sustainable use of renewable energy sources, including bioenergy. The Renewable Energy Directive contains renewable energy targets as well as sustainability criteria for solid, liquid and gaseous biofuels, covering both the land they come from and the climate performance of the fuels from a life-cycle perspective. In order to meet both climate and environmental objectives, there are specific sustainability criteria for forest feedstock used for the production of automotive and other biofuels to be considered sustainable. The Commission's proposals in the "Fit for 55" package include the following changes with a target year of 2030: Target increased to 2.2 percent for "advanced biofuels" and 2.6 for electrofuels.

- Sustainability criteria and emission calculations for electrofuels, which are proposed to reduce emissions by at least 70 percent. This applies to both "recycled carbon fuels" (from fossil carbon dioxide/ waste) and "renewable fuels of non-biological origin" (from renewable carbon sources).
- Target increased from 32 to 40 percent for the proportion of renewable energy used in the EU. Sectoral targets to be developed for transport, heating and cooling, buildings and industry.

In addition, sustainability criteria for the use of bioenergy are strengthened and Member States must design any bioenergy support systems in a way that respects the cash-flow principle for the use of forest biomass.

The Commission's proposals will be considered by the European Parliament in autumn 2021, and the way in which the use of bio-based feedstock is classified and how sustainable it is will have a major impact on the potential for using bioenergy to meet climate targets, and will also influence the conclusions and proposals for action presented in this strategy.

Also highly relevant to the efficiency improvement and electrification of the road transport sector is the EU regulatory framework on carbon dioxide emissions from new heavy-duty vehicles (Regulation 2019/1242) and passenger cars (Regulation 2019/631), which pushes for zero emission solutions in the use phase, i.e. hydrogen and battery electrification. These regulations are also part of the "Fit for 55" framework, and the Commission has proposed that emissions from new passenger cars and light-duty trucks should be reduced to zero by 2035. Emissions reductions of 30 percent by 2030 are already required for heavy-duty vehicles.

### LULUCF Regulation

Proposals on emissions and removals from forests and land under the LULUCF Regulation are part of the "Fit for 55" package, which may have major consequences for Swedish forestry and possible harvesting levels. Under the Commission's proposal, 310 million tonnes of carbon dioxide are to be sequestered in natural carbon sinks in the EU by 2030. For Sweden, the proposal means that uptake in forests and land must increase by almost 10 million tonnes per year from 2030. Under the proposal, Bio-CCS cannot be included as a carbon sink.

### The EU Emissions Trading Scheme

The EU Emissions Trading Scheme (EU ETS) aims to reduce greenhouse gas emissions in the EU in a cost-effective way. The scheme includes industrial activities as well as electricity and district heating production. Aviation within the EU is also included in the scheme, but no other modes of transport.

The Commission has proposed expanding the EU ETS to include the maritime industry, the transport sector and buildings. However, under the proposal, the transport sector and buildings will be in a separate scheme because the costs of reducing emissions are very different from the sectors included in the current scheme. Like aviation, the maritime industry will be included in the regular ETS.

### Taxes and state aid rules

The Energy Taxation Directive has an impact on the possibilities for national support for different forms of bioenergy. This directive is also part of the "Fit for 55" package, where the Commission proposes to harmonise taxation of all fuels in the EU in line with the directive. The proposal includes removing the tax exemption for aviation and maritime transport for a 10-year period and setting minimum levels of taxation based on energy content, environmental performance and area of use. However, the proposal is likely to require a unanimous decision from Member States and will therefore be difficult to get through. A revision of the state aid rules is also underway and may ease Sweden's exemption allowing tax exemptions for highly blended biofuels other than biogas. The EU Commission has currently approved continued tax exemptions for highly blended biofuels until 2022. The revision is also likely to stop many of the tax exemptions that exist for fossil fuels around Europe today.

Investments in sustainable technology development
The EU also offers significant opportunities for financing investments in the development of sustainable technologies, including those using bio-based feedstock. The most important example is the Innovation Fund, which plans to allocate about EUR 10 billion by 2030 for demonstration projects. These could be projects in

different areas, such as hydrogen, bioenergy, CCS and electrification.

## 6.2 Sweden

The main national instruments that directly affect the use of bioenergy are carbon tax, energy tax and reduction obligation for road and air transport. Many other taxes, such as the waste incineration tax, also have an impact.

It is clear that the reduction obligation, and other market-based instruments that existed before it was introduced, have been effective in increasing the use of biofuels in Sweden. However, partly because Sweden has not had corresponding production-related instruments, it has not led to a corresponding expansion of domestic production capacity. Instead, Sweden is currently heavily dependent on imports of biofuels and biofuel feedstocks, as discussed in Chapter 5.1.

In an ongoing assignment, the Swedish Energy Agency is analysing the need for additional instruments to promote biofuel plants with new technologies, including the promotion of domestic production. The Swedish Energy Agency's preliminary proposal is a targeted quota in the reduction obligation for feedstocks that cannot be converted into fuels with established technologies, i.e. feedstocks based on lignocellulose. It also advocates the possibility of investment support for production facilities, for example through Industriklivet [Industrial Leap]. There are also opportunities for aid through Klimatklivet [Climate Leap].

In June 2021, the Phase-out Inquiry (M2019:04) presented, among other things, proposals to phase out the use of fossil fuels in domestic transport and machinery in Sweden by 2040. The inquiry estimates that phase-out can be achieved through a combination of extensive electrification, reduced traffic volume through a more transport-efficient society, and a transition to long-term sustainable renewable fuels, and also includes proposals for instruments on how this can be achieved.[42]

As a first step, the Biogas Market Inquiry (SOU 2019:63)[29] has proposed production support for biogas through anaerobic digestion and upgrading of this to vehicle gas. In a second step, production support is also proposed for biogas produced through other technologies, which opens up opportunities for more feedstocks and greater potential, for example via gasification of lignocellulose.

The Government has announced that a system for operational support for bio-CCS in the form of reverse auctioning will be introduced by 2022, with the first payments for stored carbon dioxide planned for 2026. The aim is to create 400,000 tonnes of stored carbon dioxide per year. The Swedish Energy Agency has submitted a proposal for the design in a government commission and will submit a final report on the commission with further details and legislative proposals in the autumn of 2021.[43] The introduction of such support could have a major impact on the development of bio-CCS and also, in the long term, on where bio-based feedstock is used.

# 7. Impact of technology development on the role of bio-based feedstock in the transition

This chapter discusses a selection of technological solutions whose development is expected to have a major impact on the demand for bio-based feedstock in the transition to fossil freedom. The factors discussed have been divided into six different categories. The technological solutions have different implications for the sectors' demand for bio-based feedstock, as summarised in Table 3.

1. **Electrification and hydrogen in industry transition (Chapter 7.1)**
   - Electrification is expected to be an extremely important part of the transition, and is divided into direct and indirect.
   - "Direct" electrification includes various technological solutions where electricity is used to reduce the need for fuels.
   - With "indirect" electrification, energy is converted and stored chemically as e.g. hydrogen for easier use in many applications.
2. **Bio-CCUS (Chapter 7.2)**
   - May have an impact on the use of bio-based feedstock, as the storage of captured carbon dioxide can increase the competitiveness of bio-based feedstock use in certain sectors. Captured carbon dioxide can also replace the use of both fossil and biogenic feedstocks.
3. **Electrification and hydrogen in the transport sector (Chapter 7.3)**
   - Divided into direct and indirect electrification in the same way as in the section on "Electrification and hydrogen in industry transition".
4. **Circular economy – material recycling (Chapter 7.4)**
   - Recycling and reuse are a key factor in reducing

| | Electrification and hydrogen industry | Bio-CCUS | Electrification and hydrogen transports | Material recycling | Efficiency improvements | Alternative heat sources |
|---|---|---|---|---|---|---|
| Forest industry | | X | | | X | |
| Chemical industry | X | X | | X | | |
| Steel and metal industry | X | | | | | |
| Cement industry | X | | | | | |
| Transport sector and machinery | X | | X | X | | |
| Electricity and heating | | X | | X | X | X |

**Table 3** Overview of technological solutions and the sectors in which they are expected to have the greatest impact on the use of bio-based feedstock in the transition to fossil freedom.

the need for virgin materials, including bio-based feedstock.

5. **Efficiency improvement and electrification in the forest industry (Chapter 7.5)**
   - The development of the forest industry is an important enabler for bio-based feedstock use in more sectors to a greater extent than today.
6. **District heating of the future (Chapter 7.6)**
   - Alternative heat sources, such as geothermal heating, deep geothermal energy, solar heating, waste incineration and waste heat, are alternatives to district heating which could provide opportunities to reduce the use of biofuel. For some of these, heat pumps and/or energy storage may be required.
   - Efficiency improvements in the building stock combined with reduced heating needs due to climate change will result in reduced heating needs, despite population growth.

For each factor, there is a discussion on their technical and economic potential to influence the demand for bio-based feedstock. Conclusions are then drawn on how the factor is estimated to affect the amount of bioenergy used in different sectors.
A summary of the estimated need for bio-based feedstock based on the impact of the technical solutions listed above in each sector is given in Table 4.

## 7.1 Electrification and hydrogen in industry transition

The industry sector accounts for one-third of Sweden's greenhouse gas emissions. The largest emitter is the iron and steel industry, which accounts for more than 10 percent of territorial emissions. The cement industry and refineries each account for about 5 percent, while the chemical industry accounts for just under 3 percent. However, both the chemical and refinery industries also handle large quantities of fossil feedstocks, which end up in their products. Bio-based feedstock in the refinery sector is covered in the discussion of the transport sector in Chapter 7.3 and is therefore not addressed here.

### Iron and steel industry

In the iron and steel industry, hydrogen has been established for some time as the main tool on the road to fossil-free production, replacing the coke-based blast furnace process for reducing iron ore. SSAB, LKAB and Vattenfall are collaborating in the Hybrit project with a pilot plant in Luleå and plans for scale-up in Gällivare. Meanwhile, the start-up H2 Green Steel is planning a plant in Boden.
For the iron and steel industry to succeed in the trans-

| Sector | Current need, incl. net import (TWh/year) | Estimated need, incl. net import 2030 (TWh/year) | Estimated need 2045 (TWh/year) |
|---|---|---|---|
| Road transport | 27 | 49 | 1 |
| Machinery | 2 | 10 | 6 |
| Aviation and maritime industry | 0 | 3 | 6 |
| Forest industry incl. bio-CCS | 58 | 51 | 50 |
| Electricity and heating sector incl. bio-CCS | 71 | 64 | 56 |
| Chemical industry | 0 | 3 | 9 |
| Iron and steel industry | 0 | 6 | 5 |
| Metal | 0 | 0 | 2 |
| Cement industry | 0 | 3 | 0 |
| Mining and minerals industry | 0 | 4 | 0 |
| **TOTALT** | **158 TWh/år** | **193 TWh/år** | **135 TWh/år** |

**Table 4** Estimated domestic bio-based feedstock need in 2030 and 2045, based on the maximum estimated impact of alternative technological solutions described in Chapter 7. Note that the values in the table have been converted to primary energy.

ition to fossil-free production, some 4–6.5 TWh/year of processed bio-based feedstock (fuel and biochar) will be needed in steel production, even after the transition to hydrogen-based processes. Coal is used in the Höganäs process as a reducing agent, in electric arc furnaces as an alloying agent and additive, and for electrodes. These uses are considered difficult to make fossil free other than with biochar, produced from e.g. forest feedstock.

The steel industry's roadmap estimates that 2–3 TWh/year of energy gases for heating will continue to be needed. This largely involves burning biogas or other biogenetic gases in various types of furnaces.

The industry is currently investigating whether hydrogen can also be used to meet the heating need. Ovako, in cooperation with Linde Gas, demonstrated this technology in 2020 and is now looking at the possibility of implementing the technology on a large scale. Full implementation in Sweden could involve electrolysers in the 800 MWel range. The possibility of using hydrogen as a fuel may vary between companies. If the technology becomes established, the future bio-based feedstock need for the Swedish steel industry could thus be limited to 2–4 TWh/year of biochar and biofuels. The reduction of 3 TWh/year corresponds to about 50 percent of the approximately 4–6.5 TWh/year indicated as needed in Chapter 3.

### Mining and minerals industry

Like the iron and steel industry, the mining and minerals industry can replace energy gases for heating with direct electrification or indirect electrification through hydrogen. This means that the need for 2–3 TWh/year of bioenergy use indicated for 2030 could be completely eliminated by 2045.

### Cement industry

In total, the cement industry uses about 3.5 TWh of energy. In 2017, about 20 percent of the fuel used was bio-based. To fully replace fossil fuels, 4.5 TWh/year of bio-based feedstock would be required, as calculated in Chapter 3. However, not all carbon dioxide emissions from the industry come from the fuel; two-thirds are emissions from the limestone in the cement production process. CCS technology is needed to address these emissions, which requires additional energy.
A possible alternative to biofuels is the electrification of cement kilns with plasma technology. In the CemZero project, Cementa and Vattenfall have shown that there may be technical conditions for developing an electrified production process for cement in Sweden.44 The carbon dioxide released from the limestone must also be captured with CCS, but this is cheaper and more efficient with electric heating, since no flue gases are produced by combustion.

With electric heating of cement production, the need for biofuels in the process would largely disappear, and the scenario for bio-based feedstock needs made below therefore includes no bio-based feedstock for the cement industry in 2045. For 2030, however, an increased need is seen, as electrification is not expected to have been developed and implemented by then.

### Chemical industry

The chemical industry currently uses large amounts of fossil feedstocks that could be replaced by bio-based feedstock. By far the largest process using fossil feedstocks is the Borealis cracker, which produces 770 kt/year of olefins from fossil feedstocks for further processing. Olefins can instead be produced from bio-based feedstock, for example via the intermediate biomethanol through a process called methanol-to-olefins (MTO). As discussed in Chapter 3, this represents up to 25 TWh/year of biogenic primary energy if all fossil feedstocks are to be replaced. However, the industry is working on several different pathways for transition to fossil-free production. Efficiency improvements and electrification can offer great opportunities. Increased circularity is another very important factor, which is discussed under a separate heading below.

One possible alternative to bio-based feedstocks is to use carbon dioxide and electricity as feedstock through CCU. An example of this is Perstorp's initiative in Stenungssund that aims for 200 kt/year of fossil-free methanol production via a combination of captured carbon dioxide, electrolysis-based hydrogen and biogas starting in 2025. Another possible solution in Stenungssund is to replace fossil cracker fuel with hydrogen from electrolysis, either fully or partially, which could reduce the need for other feedstocks by about 2–3 TWh/year. Electrically heated processes are also of interest for further investigation in order to reduce the amount of fossil feedstock.

These are deemed to have great potential.

Companies from the chemical industry have estimated that technologies based on electrification, CCU and efficiency improvement could replace about one-third of today's fossil feedstocks. This would mean that one-third of the projected consumption of bio-based feedstock could be avoided by 2045, compared to 8–9 TWh/year of unprocessed bio-based feedstock.

## 7.2 Bio-CCUS and CCU

### Bio-CCS

The Climate Policy Roadmap Inquiry has set a goal that bio-CCS will contribute to the capture of 3–10 million tonnes of carbon dioxide/year by 2045.[1] This corresponds to 10–30 percent of today's available biogenic carbon dioxide emissions from large point sources in the forest industry and district heating and CHP production.[45] Thus, the Climate Policy Roadmap Inquiry's goal of up to 10 million tonnes/year of bio-CCS can be achieved even if considerably less bio-based feedstock is used for heat production than today. However, there may be an increased need for fuel to drive the process itself.

Large-scale carbon capture is advantageous from a cost perspective. Geographical location and access to infrastructure are also crucial, as they affect the cost of transporting the carbon dioxide prior to storage.

This type of large point emission source is currently found in the forest industry.[45] The energy consumption for capture can be around 3 MJ/kg of carbon dioxide with current technology. Achieving half of the bio-CCS target in the forest industry may require 1.5–5 TWh/year in increased fuel demand in 2045 and about 1 TWh/year in 2030. This energy need can technically also be met with electricity, as discussed for the district heating sector below, but this is less likely in the forest industry and this bio-strategy is based on the assumption that bioenergy is used. Energy consumption is discussed in Chapter 7.5 in the context of efficiency improvements in the forest industry.

District heating and CHP production also have large point sources of emissions and, like the forest industry, can contribute to achieving the bio-CCS target.[1] However, there is an opportunity for efficiency improvements by combining electrification and smart integration with district heating, which is one of the aspects Stockholm Exergi is investigating in its study on bio-CCS in its Värtaverket plant. This could save 0.5–2 TWh/year of fuel when capturing 1.5–5 million tonnes/year in connection with district heating production. The implementation of bio-CCS can thus be said to come together with a partial electrification of heat production.

### Bio-CCU and CCU

The carbon dioxide captured can also be used as feedstock for new products in e.g. the chemical industry (see Chapter 7.1), as well as for so-called electrofuels in the transport sector. The carbon dioxide can be of either fossil or biogenic origin. In some markets, bio-based carbon dioxide already has a higher value than fossil carbon dioxide, and could in the long term become an important source of carbon for society.

The electrofuel-based drop-in fuels can be used in conventional internal combustion engines and existing distribution systems. Examples of fuels that can be produced are drop-in diesel, drop-in petrol, drop-in aviation fuel and gas (methane). Ammonia and methanol are alternative electrofuels currently being developed, particularly with marine applications in mind. There are several industrial initiatives for electrofuel production facilities in Sweden and neighbouring countries today. Examples include Liquid Wind in Örnsköldsvik and Jämtkraft in Östersund.

## 7.3 Electrification and hydrogen in the transport sector

There are two main options for the electrification of the transport sector: battery-based electrification and hydrogen-powered vehicles and vessels.

### Battery-based vehicles

There is currently a very strong development in battery-based vehicles for road transport. For passenger cars, battery electric vehicles already have significant and rapidly growing market shares. In 2020, 32 percent of newly registered passenger cars were rechargeable (fully electric cars or plug-in hybrids), compared to 11 percent in 2019, while the share for trucks is still very small.[46] The energy efficiency from grid electricity to useful energy for battery electric vehicles is high, around

70-80 percent, making battery-based electrification a resource-efficient alternative in a world where the demand for various forms of renewable energy is high. An accelerating trend towards more battery-based electrification is also being seen within aviation and the maritime industry.

### Hydrogen

Many vehicle manufacturers believe that hydrogen-based fuel cell vehicles will be relevant in the longer-term heavy transport segment and are currently making major investments in this area.[47] The efficiency from electricity to useful energy for propulsion is around 30–40 percent for hydrogen fuel cell vehicles today, i.e. about half that of battery-based vehicles. However, the range of hydrogen vehicles is longer than that of battery-based ones. For aviation, hydrogen is seen as a viable option, although considerable technological development is required. For the maritime industry, hydrogen is also a potential alternative in the long term, but more efforts are currently being made with other renewable alternatives.

### Costs of transport sector transition

The realisable potential of battery electrification, hydrogen and electrofuels in the transport sector will be determined in competition with biofuels.
A recently published research study[48] predicts that battery vehicles will have the lowest transport costs for heavy-duty vehicles in both 2030 and 2045; see Table 5. The cost of hydrogen and electrofuel-powered vehicles in 2030 is higher than both batteries and biofuels. In 2045, hydrogen fuel cell vehicles may come down to about the same cost as biofuels. It should be stressed that these cost projections are highly uncertain, especially for the longer time horizon to 2045.

Battery electrification is thus expected to take hold where it is technically feasible in the road transport sector. Hydrogen is expected to play a certain role in longer and heavier transport. For other sectors, maritime and aviation, the situation is different, as a larger share of transport is expected to require liquid or gaseous fuels even in the longer term. However, electrification on shorter distances is relevant for both aviation and shipping.

The production of hydrogen and electrofuels requires large amounts of electricity, and presupposes the expansion of wind and solar power. Producing 1 TWh of hydrogen for vehicles requires about 1.3–1.4 TWh of electricity. The corresponding figure for electrofuels is around 1.5–1.6 TWh. If the production plants are built in the right location, there is the possibility of recovering large parts of the losses as district heating.
In Fossil Free Sweden's hydrogen strategy, the

| Vehicles | Fuel | 2030 SEK/vkm | 2045 SEK/vkm |
|---|---|---|---|
| Battery electric vehicles* | Electricity | 4,4 | 3,8 |
| Internal combustion engine | Diesel (fossil ref) | 4,4 | 4,3 |
| Internal combustion engine diesel/DME | Biofuel | 4,6 | 4,4 |
| Internal combustion engine compr. gas | Biofuel | 5,0 | 4,5 |
| Fuel cell | Hydrogen | 5,9 | 4,6 |
| Internal combustion engine diesel/DME | Electrofuel | 5,9 | 5,0 |
| Internal combustion engine compr. gas | Electrofuel | 6,5 | 5,4 |
| Internal combustion engine diesel/DME | Electrofuel | 5,9 | 5,0 |
| Internal combustion engine compr. gas | Electrofuel | 6,5 | 5,4 |

**Table 5** Projected total transport costs, expressed as cost per vehicle kilometre (SEK/vkm), for different vehicle and fuel options for long-distance heavy (40 tonne) road transport in 2030 and 2045.

**Source:** Swedish National Road and Transport Research Institute (2021), "KNOGA – Fossiloberoende framdrift för tunga långväga godstransporter på väg – kostnadsfördelning och risker för olika aktörer" [KNOGA – Fossil-independent heavy long-distance freight transport by road – cost distribution and risks for different actors].[48]

* The "large battery, fast charging" case from the study.

Government has set a planning target of at least 8 GW of electrolysis capacity by 2045. By comparison, 1 GW of electrolysis capacity can provide about 2–4 TWh/year of electrofuels or 3–6 TWh/year of hydrogen.

### Electrification scenarios

There are different scenarios for the speed and scale of electrification of the road transport sector. The automotive industry's roadmap for passenger cars sets a target of 80 percent of new car sales to be plug-in electric vehicles by 2030. Power Circle forecasts a higher rate, and that 90 percent of new car sales will be fully electric cars by 2030. They also estimate that plug-in hybrids will be phased out by then.[49] This is a rate of increase that would mean that around 85 percent of the entire passenger car fleet will be battery powered by 2045. The Swedish Transport Administration's scenarios for 2040 show 68–84 percent battery-powered passenger cars. There is thus a consensus on a high electrification of at least 70 percent of passenger cars by 2045, which has been chosen here as the low scenario, with 100 percent as the high scenario; see Table 6.

For freight transport, the uncertainty is greater, but there is very rapid development. Several manufacturers offer battery-powered models of both buses and trucks, and in 2021 Volvo Trucks will also launch battery-powered heavy-duty trucks. According to the Swedish Transport Administration's scenarios,[50] 10 and 30 percent of freight transport will be carried out by electrified vehicles in 2030 and 2040 respectively, which has been chosen here as the low scenario; see Table 5. According to the automotive industry's roadmap for heavy transport, in a high-electrification scenario, electric vehicles are expected to account for 50 percent of new vehicle sales already in 2030, indicating that the share of electrified heavy-duty vehicles could be significantly higher by 2045. Discussions with the industries indicate that as high as 95 percent is possible, which was chosen as the high scenario for 2045; see Table 6. For very heavy and long-distance transport, for example in the forestry industry, hydrogen propulsion may become relatively more important due to difficulties with battery-based electrification.

Machinery is an important category, which is divided into different types of machines and use in different sectors with different potential for electrification. Construction machinery, which accounts for more than one-third of carbon dioxide emissions, has good potential for electrification and there is already extensive development.[51] Volvo CE launched fully electric models of both smaller wheel loaders and smaller excavators in 2020. In some industries, such as mining, electrification is already well advanced, and the industry estimates that machinery could be close to fully electrified by 2035. Electrification of other types of machinery, such as tractors and forestry machinery, is more challenging.

### Implications for biofuel need

The results of the analysis in Figure 6 clearly show that the rate of electrification has a very strong influence on the amount of biofuels required, especially for 2045. The results, which also include the Transport Adminis-

| | Low electrification | | High electrification | |
|---|---|---|---|---|
| | **2030** | **2045** | **2030** | **2045** |
| Machinery | 10% | 50% | 25% | 75% |
| Passenger cars | 30% | 70% | 50% | 100% |
| Buses | 30% | 75% | 70% | 95% |
| Trucks | 10% | 30% | 20% | 95% |

**Table 6** Electrification scenarios – the figures indicate the share of traffic work for each type of vehicle carried out using electricity as fuel. The low electrification scenarios are based on the Swedish Transport Administration's scenarios for achieving the climate target for domestic transport.[50] The high electrification scenarios are based on individual discussions with industries and companies.

tration's scenarios for traffic work growth,[52] also clearly show that the need for biofuels will increase until 2030 to meet the 70 percent target for the road transport sector, regardless of the scenario. Vehicles are used for a long time before they are replaced, and even if new sales of electric vehicles are high, by 2030 there will still be many vehicles with internal combustion engines that need access to sustainable fuels with a low carbon footprint.

The difference between the 2045 scenarios is about 20 TWh/year of fuel, which corresponds to about 30 TWh/year of unprocessed bio-based feedstock – a large share of the domestic potential. A very high rate of electrification implies a low demand for biofuels by 2045, regardless of transport developments.

### Overall potential for electrification of the transport sector

The bio-strategy has based its estimates of the transport sector's biofuel need on the scenarios of high electrification and high transport work in Table 6. In summary, the estimated biofuel need in 2030 could be around 35 TWh/year (refined energy) for road transport and machinery. For 2045, it may be possible to reduce the need to as low as 5–6 TWh/year (refined energy), most of which would be used in machinery. For 2045, this need is 35 TWh/year less than the need for road transport and machinery, as presented in Table 1 in Chapter 3.

For the aviation and maritime sectors, battery-based electrification is relevant in niche applications, such as some regional air routes and ferry services. It is unlikely that electrification will reduce the need for liquid fuels to a greater extent in these transport modes by 2045. Domestic transport fuel use is around 2 TWh/year in the aviation sector and around 1.5 TWh/year in the maritime sector. For international transport, the amount of fuel used in Sweden is much higher: about 10 TWh/year for aviation (before Corona) and about 24 TWh/year for maritime transport.

## 7.4 Circular economy – material recycling

The circular economy is a key issue in reducing the need for virgin materials, including bio-based feedstock. Today, 50 percent of total household waste goes to energy recovery (incineration), while about 35 percent is recycled.[53]
Working towards a circular economy, where materials

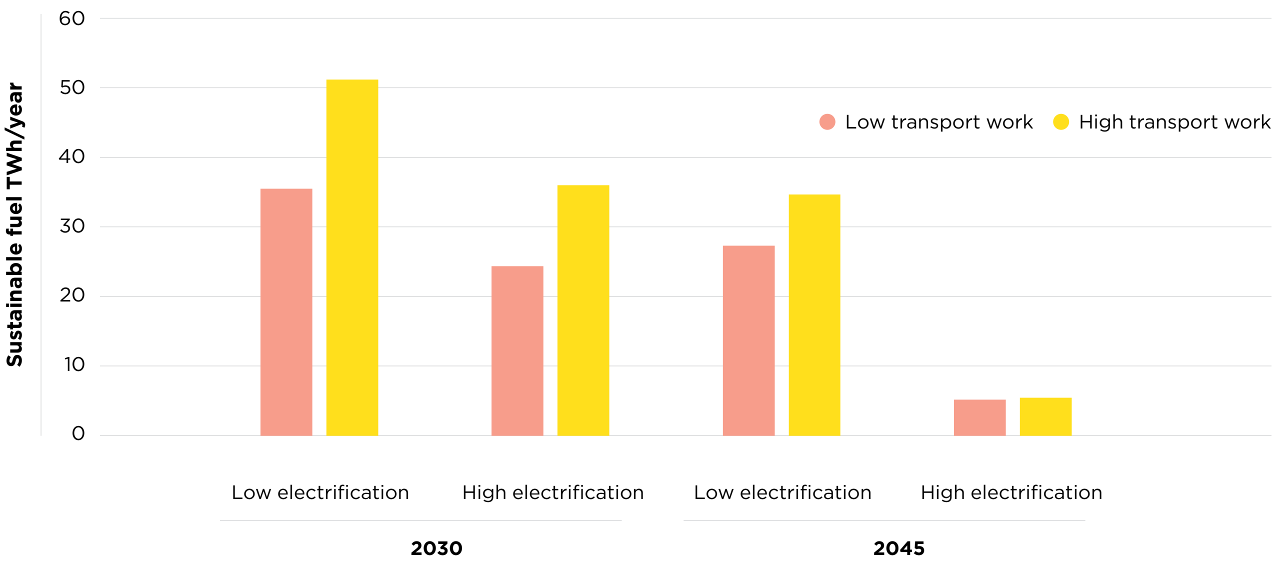



**Figure 6:** Estimated future need for liquid or gaseous sustainable fuels for road transport and machinery for low and high transport work. This need can be met by biofuels, electrofuels or hydrogen. The bio-strategy has based its estimates of the transport sector's biofuel need on the scenarios of high electrification and high transport work.

are used more efficiently to reduce the removal of new feedstocks and reduce waste volumes, can lead to a change in composition and lower waste volumes in the longer term. For example, the EU recently introduced a levy on non-recycled plastic packaging and has set a target of 50 percent recycled by 2025. The EU waste package also includes a target for recyclable municipal waste in particular, with zero percent going to landfill starting from 2030.

Longer product and material lifetimes, more reuse and resource- and energy-efficient processes are essential to achieving a more circular economy. In such a system, energy recovery through waste incineration is only used when products cannot be further circulated.

### Recycling in the chemical industry

Today, the Swedish chemical industry uses virgin fossil feedstock almost exclusively, mainly for the production of plastics, base chemicals and speciality chemicals. A transition to fossil freedom based on bio-based feedstocks would require very large quantities, as discussed in Chapter 3.

An important part of the circular economy that can have a significant impact on the use of bio-based feedstock in a fossil-free society is the recycling of plastic materials. Today, only 16 percent of plastic waste is recycled. Technological developments and increased source separation are expected to increase the proportion of plastics that can be mechanically recycled, but there will still be a large fraction of plastic waste where this is not possible.

The Swedish chemical industry is therefore investing, in parallel with developments to use biogenic raw materials, in the development of a so-called recycling refinery with chemical recycling of plastics. Here, plastics that cannot be mechanically recycled will instead be chemically recycled and become the feedstock for new plastics. Borealis has conducted several studies on the possibility of converting plastic waste into a form that can be used as a feedstock and was granted support from Industriklivet in the spring of 2021 for a feasibility study on the construction of a pyrolysis-based recycling refinery.

Several companies in Europe are investing in chemical recycling of plastics, such as Neste, Total, Fortum and BASF. Neste aims to use 1 Mt/year of recycled plastic by 2030 and Total aims to have 30 percent of its plastic production circular by the same year.

Companies in the chemical industry have estimated that technologies based on chemical recycling of plastic waste have the potential to replace about one third of today's fossil feedstocks, equivalent to about 8 TWh/year of unprocessed bio-based feedstock.

Together with the third that can potentially be achieved through electrification and efficiency improvement (see Chapter 2.1), this means that there remains one-third of the fossil feedstocks used in Stenungssund that need to be replaced with biogenic feedstocks.

## 7.5 Efficiency improvement and electrification in the forest industry

The trunk of a felled tree is used as sawlogs and pulpwood. More than half of the trunk becomes sawn timber and pulp. The rest becomes residues and by-products such as bark, sawdust and lignin, which are currently used mainly for the industry's own energy supply (see Chapter 2). The forest industry uses just under 60 TWh/year of process heat from the combustion of these. The forest industry's roadmap points to efficiency improvement and new technologies in the industry as an opportunity to reduce its own energy needs. Efficiency improvement can be achieved by switching to more energy efficient technologies (as part of maintenance/new investments), but also in part through electrification. This increases the volumes of residues and by-products from the forest industry that can be used outside the traditional forest industry processes, e.g. for biofuel production, in the chemical industry or in the steel industry.

The forest industry has an efficiency potential that can be realised if investments in equipment with modern technology are made. An efficiency improvement rate of 1–2 percent per year by 2030 would result in savings of 6–12 TWh/year of biofuel, which could then be released with production of sawn timber and pulp at about the same rate as today. This implies a potential 30–60% increase in bio-based feedstock from forests that can be used outside the forest industry, compared to today's approximately 18 TWh/year. To realise this potential, the right incentives must be in place. For example, the value of the residues that can be released must be sufficiently high.

Historically, these efficiency rates are not optimistic. For example, Södra Skogsägarna has reduced heat consumption in the production of pulp and sawn products by 3 percent per year over the last five years.[54] However, as discussed in Chapter 7.4, an increased fuel demand of about 1 TWh/year is expected to cover the heat need for bio-CCS, so the available, released amount could be 5–11 TWh/year in 2030.

In the longer term, after 2030, it is reasonable to assume that the expected shift of the forest industry towards higher proportions of cross-laminated timber, packaging and textile fibres will lead to a slight reduction in the share of pulp mill by-products. For 2045, a total of 10–16 TWh/year less residues than today are estimated to be used for the industry's own energy supply.[27] Once the 1.5–5 TWh/year increased fuel need for bio-CCS is deducted, the available, released amount is 9–11 TWh/year in 2045.

The release of bio-based feedstock here refers to both increased sales of by-products and residues from plants with energy surpluses, such as sawmills and modern pulp mills, and reduced imports of biofuels to plants with energy deficits, such as integrated pulp and paper mills. It is likely that some of this released feedstock will be upgraded into new products in connection with the forest industry and in its own operations.

In addition to the potential quantified above, there is also the potential for more transformative energy saving measures, in particular through electrification. Clean electric boilers for process steam are already in use, but even higher energy efficiency can be achieved with heat pumps to supply those parts of the process that need heat at relatively low temperatures, such as paper machines, evaporators and wood dryers.

These have the potential to replace large amounts of biofuel with electricity, but their realisation depends on several factors, including the price evolution of bio-based feedstock and electricity, and is therefore not included in the efficiency improvement potential of this strategy.

The potential for energy efficiency improvements and electrification in the forest industry, before the need for bio-CCS fuel is taken into account, is thus 6–12 TWh/year of bio-based feedstock up to 2030, which represents 10–20 percent and 10–16 TWh/year (15–25 percent) by 2045.

## 7.6 District heating of the future

The heating industry is strongly market-driven and currently uses a considerable amount of fuels that are difficult to use for other applications and therefore have a lower cost, such as various types of waste and biogenic residues.

Bio-based heat production has high energy efficiency, especially when combined with renewable electricity production in CHP plants that contribute to plannable electricity production. It is important that these plants can be fully used for electricity production at times of peak electricity demand, which often coincides with high heat demand. Today, electricity production is sometimes not prioritised at these times for cost or capacity reasons.[55]

As the prices of bio-based feedstocks increase, there are good reasons to refrain from using more biofuel combustion to produce district heating without simultaneous production of electricity. In 2015, about 15 TWh/year of biofuel was used for district heating production without electricity production in so-called hot water boilers, both as base load and peak load.[56] Another important part of the heating system today is heat pumps to use low-temperature heat for heating homes and premises, with small-scale geothermal heating as an important example.

### Efficiency improvements and climate change

Energiforsk's project "Klimatförändringarnas inverkan på fjärrvärme och fjärrkyla" [Climate change impacts on district heating and cooling] has estimated the reduction of total heating need as a result of climate change to be about 3 TWh/year at 1.5 degrees of warming.[57]

Together with the expected efficiency improvements of 12 TWh/year indicated by the Swedish Energy Agency,[58] this means a reduced heating need despite population growth. The combined effect of a larger building stock and the reduced specific heating need for residences and premises is estimated at around 5 TWh/year in 2030 and around 7 TWh/year in 2045.
District heating accounts for about half of the total hea-

ting need, so the district heating need could be reduced by about 2–3 TWh/year in 2030 and about 3–4 TWh/year in 2045 thanks to efficiency improvement measures and reduced heating need due to climate change.

### Geothermal energy and geothermal heating

Deep geothermal heating is a technology considered to have the potential to provide sustainable district heating at low cost and is being investigated by several energy companies.[59] The technology can provide district heating through boreholes several kilometres deep without the need for a heat pump, but has relatively low technological maturity for Nordic geological conditions. The cost of deep drilling is currently high and needs to be reduced for the technology to become competitive. The conditions for deep geothermal heating are also highly dependent on ground conditions, limiting its use depending on location.

### Waste heat

High-temperature waste heat from industries is already widely used today, where geographical and economic conditions allow. The IVA20 identifies the need to use waste heat in traditional industry to a greater extent than is currently the case, and there are a number of areas where the potential for increased utilisation of waste heat could be significant by 2030 and 2045:

- Biorefineries, producing e.g. biofuels, generally generate large amounts of waste heat that can be used for heating if the location of the plant allows. The production of 1 TWh of fuel can produce as much as 0.3 TWh of heat. A promising possibility being explored in several places in Sweden is to co-locate biofuel production with CHP plants, which can reduce costs and facilitate the use of existing infrastructure.
- Production of biochar from bio-based feedstock can be combined with heat production, as demonstrated by Stockholm Exergi and the City of Stockholm.
- Fossil Free Sweden's hydrogen strategy sets a target of 8 GW of electrolysis capacity by 2045, which can provide up to 10 TWh/year of heat. However, there is a risk that large parts of the capacity will be located in locations that make waste heat difficult to exploit.
- An expected large expansion of data centres offers the potential to capture all the heat that is cooled down. This technology is already used in Stockholm on a small scale.

If the waste heat occurs at a lower temperature, a heat pump will have to be used in many cases, but new energy-efficient buildings and low-temperature district heating networks can more easily use low-temperature waste heat for heating.

With planned fossil-free electricity production, CHP contributes to a stable renewable energy system. A shift to a greater share of waste heat-based district heating means a reduction in such plannable production and potentially an increase in electricity consumption, where waste heat is at low temperature and requires heat pumping. Thus, it is of high importance that the electricity system is taken into account when new sources of heat production are discussed and analysed.

The Swedish Energy Agency estimates the potential for low-temperature waste heat at 9 TWh/year in 2050 and proposes that low-temperature waste heat should be included in the Act (2014:268) on Certain Cost-Benefit Analyses in the Energy Sector.[56]

### Solar heating

Solar heating is used to a very limited extent in Sweden, but has been highlighted as a technology with potential for large-scale use in district heating networks. An IEA analysis[60] of the potential of the technology has focused on small towns, partly because space constraints may limit its use in large cities and also because of the greater availability of waste heat in cities. In Europe, there are about 400 plants producing about 1 TWh/year.[61] There is no commercial installation in Sweden, but a demonstration project is underway in Härnösand, funded by the Swedish Energy Agency.

Like solar electricity, solar heating has limitations, as solar radiation does not align with heat need. Solutions where solar heating is important during the winter season therefore require a thermal store, which increases costs. At the same time, development work is underway that can be expected to reduce the production costs of solar heating. The IEA estimates the potential for solar heating without seasonal storage in Sweden at 1.5–2 TWh/year.[60] The Swedish Society for Nature

Conservation[62] estimates the potential for solar heat-based district heating at 8 TWh/year in Sweden, and the Swedish Energy Agency has an ongoing assignment to assess the potential for solar heating in Sweden, to be reported in the autumn of 2021.[63]

### Waste incineration

Waste incineration is an important contribution to district heat production today, and may increase, at least in the short term. Working towards a circular economy where materials are used more efficiently to reduce the removal of new feedstocks and reduce waste volumes (as mentioned in Chapter 7.4) will probably lead to a change in composition and lower waste volumes in the longer term.

Waste incineration will continue to be the final solution when products have reached the end of their life and cannot be circulated further, and in Sweden there are good opportunities to dispose of waste, both from Sweden and other parts of the EU, with high cost and energy efficiency through the well-developed district heating system. If incineration is also carried out using CCS, the climate impact is minimised. In the scenarios presented in this strategy, waste incineration is therefore assumed to remain at approximately the same levels as today.

### Overall potential of district heating of the future

Overall, there are several possibilities for reducing the amount of biofuel used for heating, as outlined above. This may be due to natural market developments and the development of new technologies. Climate change and energy efficiency improvements are also reducing the overall need for heating.

The amount of available (cheap) waste heat will increase with the production of fuels and hydrogen, and as a result of new data centres. Solar heating and geothermal energy will be further developed and become cheaper. There are also “difficult” fractions of (bio)waste that cannot be used for fuel, but are suitable for incineration.

Two technological factors that facilitate efficiency improvement in the district heating sector are energy storage and low-temperature district heating networks. Energy storage, such as borehole storage, provides opportunities to move heat between seasons and can facilitate the implementation of many of the options discussed above, as it allows the use of different forms of heat even in summer. At the same time, the price of bio-based feedstock will increase as demand from transport and industry increases. This increase in the cost of bio-based feedstock will cause district heating companies to gradually look for cheaper energy sources.

It is difficult to predict exactly which technologies will be adopted, but overall it is estimated that the use of biofuels in the heating sector could be reduced by up to 15 TWh by 2045. However, this does not mean that the heating system will reduce the actual use of biofuel by the same amount, as much of the waste heat that will be used will come from the increasing production of biofuel.

The reduced need for district heating is linked to efficiency improvements and climate change and, in combination with the implementation of bio-CCS, offers the potential to save about 3.5–6 TWh/year of biofuel; see Chapter 7.2 on the potential of bio-CCS in the heating sector. This can be completed with e.g. about 3 TWh/year from conversion from biomass boilers to heat pumps in detached houses and multi-family properties, and 6 TWh/year of converted district heating in a combination of waste heat, solar heating and geothermal energy. The waste heat is expected to come mainly from the new sources discussed above, such as biorefineries.

CHP plants are located in close proximity to the electricity use and contribute to plannable electricity production. They are thus an important complement to wind and solar energy, and current combined heat and power production from biofuels is likely to continue in the long term.

For 2030, the potential for new technologies to make an impact is less. The scenario presented for 2030 includes 2 TWh/year of small-scale heat pumps to replace combustion and 2 TWh/year of new technologies in district heating together with the reduced district heating demand of 2-3 TWh/year.

# 8. Conclusions

## 8.1 A possible solution to the puzzle

Bio-based feedstock makes it possible to switch out feedstocks or fuels already in the relatively short term, and is one of the key components in the transition to a fossil-free Sweden. Many sectors point to the increased use of bio-based feedstock as an enabler for their transition, but when the increased need exceeds is summed up, the need exceeds the supply of Swedish bio-based feedstock for energy purposes.

From a global perspective, Sweden has a relatively large supply of bio-based feedstocks. In a changing world, the demand for bio-based feedstock is expected to increase, which also means there is an increased risk of losing biodiversity and other negative environmental impact. The fact that Sweden will eventually become an exporter of bio-based products for energy purposes and industrial use makes the premises for a sustainable supply of bio-based feedstock discussed in Chapter 1.3 even more important.

There are a number of areas of development and new technologies that have the potential to reduce the need for bioenergy, as presented in the industries' roadmaps for fossil free competitiveness. The impact of these factors on the use of bio-based feedstock are presented in Figure 7 for 2030 and Figure 8 for 2045. They should not be seen as a forecast of future developments, but rather show a possible solution to the puzzle of demand and supply of bio-based feedstock.

### Development up to 2030

The need for bio-based feedstock in 2030 will be significant in the three sectors industry, transport and electricity/heating. Like today, the largest use in industry will be by far in the forest industry. However, the

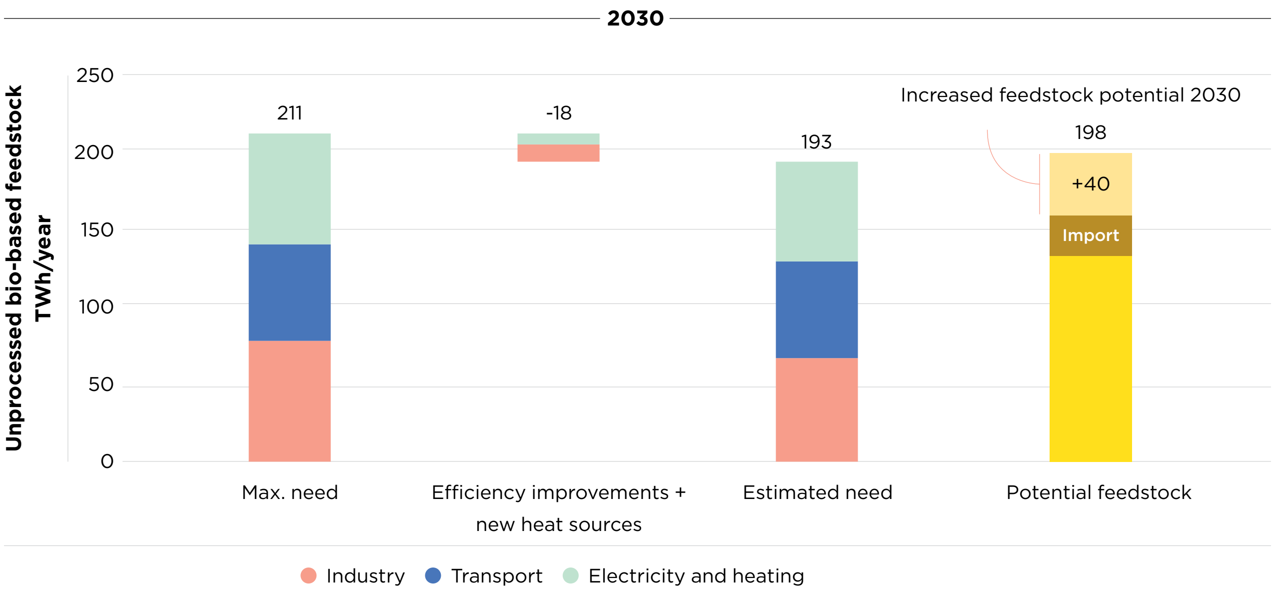



**Figure 7:** Estimated need for bio-based feedstock in unprocessed form 2030. The maximum need is based on roadmaps and published studies; see Chapter 3. Note that net imports are assumed to remain at current levels. The same applies to the use of biogenic waste, in particular in the heating sector. The input values in the diagram are based on maximum estimated need and maximum estimated impacts of measures.

steel, mining, cement and chemical industries may also have started to use bio-based feedstock to a greater extent than today. In the transport sector, there is a major need for the transition of road transport and machinery to meet the 70 percent emission reduction target by 2030, but also some use in aviation in line with aviation's reduction obligation.

By 2030, the use of bio-based feedstock in electricity and heat production is expected to be slightly lower than today due to increased use of small-scale heat pumps to replace small-scale combustion, some increased use of waste heat and other alternative heat sources, and a reduced need for district heating.

The high need for bioenergy, particularly in the transport sector, means that biofuel imports are likely to remain at current levels in 2030. However, it will account for a smaller share of the total volume of biofuels used, as domestic production is expected to increase from around 5 TWh/year today to more than 30 TWh/year in 2030.

Fuel imports, which are expected to continue to be dominated by HVO diesel, pose a risk of lower sustainability quality of fuels. This is particularly true given the large increase in demand for renewable fuels expected worldwide by 2030 and the pressure this will put on the sustainable supply of feedstocks. Maintaining relevant sustainability criteria will be of paramount importance for these volumes, as well as for domestic production.

In total, the Swedish need for bio-based feedstock in unprocessed form in 2030 will be about 35 TWh/year higher than today, while maintaining net imports of about 26 TWh/year. This corresponds to a 22 percent increase compared to current use of bio-based feedstock.

### Development up to 2045

By 2045, the need for biofuels in the road transport sector is expected to be greatly reduced due to electrification. For domestic aviation and shipping, the need will have grown slightly. The need for bio-based feedstock will have also increased within industry, especially in the chemical industry, which is likely to carry out much of its transition after 2030. The iron and steel industry

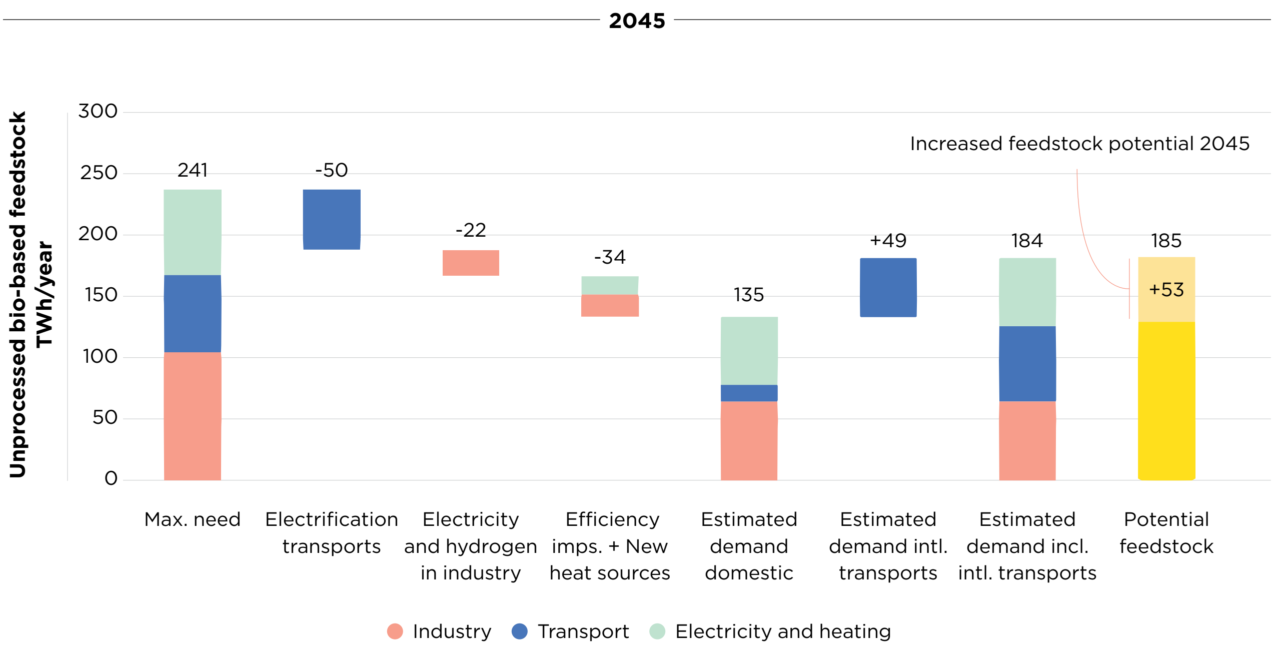



**Figure 8:** Estimated need for bio-based feedstock in unprocessed form 2045. No net import is assumed. The use of biogenic waste, especially in the heating sector, is assumed to remain at current levels in 2045. The maximum need is based on roadmaps and published studies; see Chapter 3.

will have some need for bio-based feedstock to make the transition to fossil-free steel, while the need in the cement industry may disappear through electrification. The electricity and heating sectors have the potential to reduce their use of bioenergy through efficiency improvements and new heat sources.

In total, the domestic need in 2045 may be about 20 TWh/year less than today, which means that it is possible that Sweden will be independent of net imports of bio-based feedstocks for energy purposes. These figures are well within the estimated available potentials presented in Chapter 4.

For 2045, where the estimated increased potential for bio-based feedstock is more than 50 TWh/year while domestic demand is relatively small, there are also opportunities for exports based on Swedish bio-based feedstock, or alternatively that large parts of the need for the international transport that refuelled in Sweden are also produced here. This is about 10 TWh/year for aviation and 24 TWh/year for shipping, which makes a total of about 49 TWh when converted to primary energy. However, it is possible that growth in certain industry sectors will result in increased need for bio-based feedstocks in 2045 that has not been included in the estimates in this strategy. The total need in 2045, including international aviation and shipping, is estimated at about 184 TWh, which represents an increase of 16 percent compared to the current use of bio-based feedstock. A comparison between the current use of bio-based feedstock and the estimated future needs for 2030 and 2045 can be seen in Figure 9.

## 8.2 Value and willingness to pay for agricultural and forestry by-products and residues

Forestry in Sweden is primarily carried out for the purpose of producing sawn wood products, pulp and paper, as this is where the economic value lies. The amount of available bio-based feedstock thus depends on the traditional forest industry, a situation that is not expected to change in the foreseeable future. Efficient use of harvested forests by also using the residues and by-products generated contributes to the transition to a fossil-free society, while at the same time strengthening Swedish competitiveness and welfare. In agriculture, more efficient use of by-products and land can serve the same purpose.

Since these by-products and residues are such a valuable resource in the transition, with the potential to

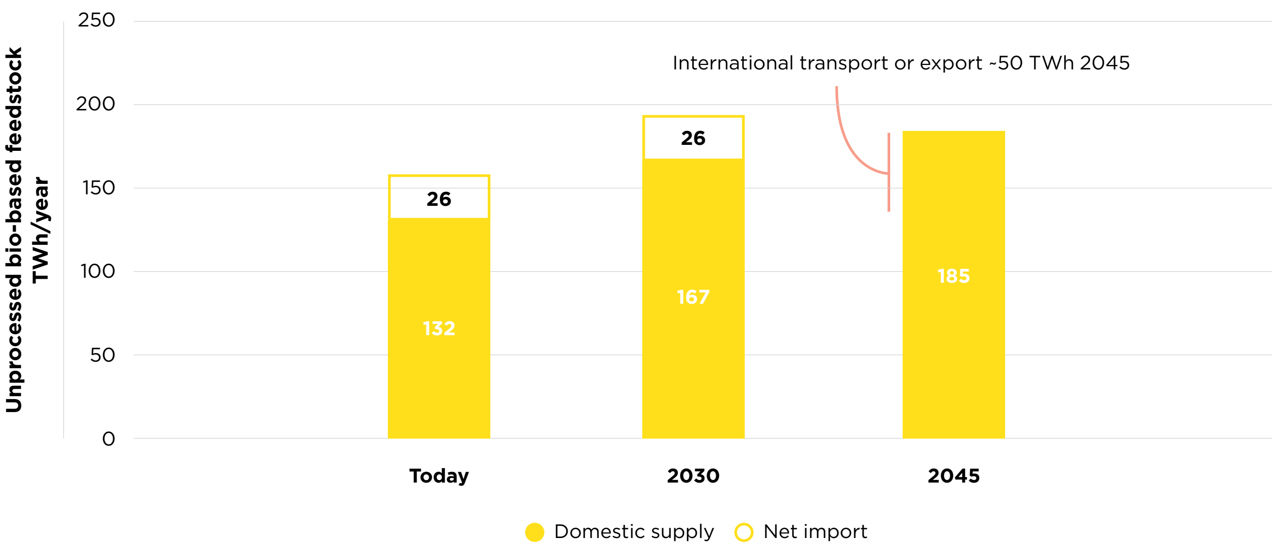



**Figure 9:** Current use of unprocessed bio-based feedstock compared to estimated total need by 2030 and 2045. International transport includes the aviation and maritime transport, and is estimated to be supplied with domestically produced fuel by 2045.

replace fossil materials and energy with fossil-free alternatives, they should primarily be used to replace fossil carbon atoms where there are no other alternatives, for example as feedstock in the chemical industry. This is also likely to happen as increased demand for bio-based feedstock, together with policy instruments at both the national and European level, will influence prices, and the willingness to pay is likely to be highest in those sectors where fossil-free alternatives are lacking or have very high costs.

### Biofuels in the transport sector

Biofuels will play a crucial role in Sweden's ability to reach the target of a 70 percent reduction of emissions from the transport sector by 2030, compared to the 2010 level. Biofuels are a solution that can be implemented relatively quickly, as they can in many cases be used in existing vehicles and infrastructure. Based on the set levels in the reduction obligation, the transport sector is expected to be a very large user of bio-based feedstock by 2030, estimated in the strategy at around 35 TWh/year, which means around 49 TWh/year when converted to primary energy. Even if new sales of electric cars are high in 2030, there will still be many internal combustion engines in the fleet. A prerequisite for reducing climate emissions from these vehicles is therefore the availability of sustainable, low-carbon fuels even after 2030. The reduction obligation for aviation also implies a need for biofuels beyond 2030.

There is significant potential to increase domestic production of biofuels, mainly based on by-products and residues from the forest industry and possibly also energy crops. However, investments in biofuel production require a longer time horizon than 2030 to materialise. Although the need for biofuels for road transport is expected to remain to some extent beyond 2030, electrification will almost certainly take over an increasing share of the transport sector. By 2045, it is estimated that 100 percent of passenger cars and about 95 percent of heavy transport, excluding machinery, will be electrified. To make the economics of the plants needed to meet the biofuel need in 2030 work, they need to be able to export their production in increasing quantities after 2030, or be able to switch or combine production with other products, such as biojet for aviation, fuel for shipping, or renewable feedstock for the chemical industry.

The energy carriers used in the production of biofuels are in many cases similar to the intermediate products used in the chemical industry as well as those used in the production of aviation fuel.

### Bio-based feedstock for the chemical industry

The Swedish chemical industry produces mainly plastics, base chemicals and speciality chemicals, and currently almost exclusively uses fossil virgin feedstock for production. The potentially largest volumes of bio-based feedstock in the industry sector may therefore be required in the chemical industry. A transition of the chemical industry to fossil freedom through efficiency improvements, CCU, electrification and chemical recycling is estimated to require around 9 TWh/year of bio-based feedstock by 2045.

Current policy instruments direct bio-based feedstock to the transport sector, and the use of biogenic feedstocks for the chemical industry is therefore not on the same footing as the transport sector. As in refineries, most of the chemical industry's fossil inputs do not become carbon emissions, but end up in products such as plastics. However, the willingness to pay that currently exists for fuels and that is created by reduction obligations and tax exemptions does not exist here.

### Release of bio-based feedstock through efficiency improvements in the forest industry

Efficiency improvements in the use of bio-based feedstocks for energy purposes in the forest industry occur naturally as part of the maintenance and new investments required when old technology is replaced by new. In this strategy, these efficiency improvements are estimated to be in line with historical levels and lead to 6-12 TWh/year of bio-based feedstock being released in 2030 if the production of sawn timber and pulp remains at current levels. For 2045, 10-16 TWh/year of bio-based feedstock is estimated to be released.

Further efficiency improvements can release more bio-based feedstock than estimated here if the economic incentives are high enough, i.e. the value of the bioenergy that can be released is higher than the cost of the investment. Thus, the price of the forest industry residues that can be released will determine whether such further efficiency improvements take place.

The efficiency improvements release bio-based feedstock that can be used outside the traditional forest industry processes, e.g. for biofuel production, in the chemical industry or in the steel industry. The prices of bio-based feedstock and electricity affect how the released bio-based feedstocks will be used. They can be used to expand production, replace electricity use, or for sale.

### The heating sector's role in the transition

District heating plays an important role in the transition to a fossil-free Sweden. It can use residual energy, and also low-value heat to an increasing extent, from industries, data centres and other operations. At the same time, district heating can contribute to highly efficient, plannable and renewable electricity production through bio-based CHP. The bio-based CHP production also has the potential to develop into biorefineries where biofuels are co-produced with electricity and heat,64 and to be a cost-effective alternative to negative emissions through bio-CCS.

Higher demand and competition for bio-based feedstocks combined with lower renewable electricity prices means a likely transformation of the district heating sector. Efficiency improvements, reduced heating needs due to climate change, waste heat and new technologies, such as solar heating and geothermal energy, may make it attractive to replace biofuels for district heating with other heat sources. The development of cost-effective energy storage provides opportunities for seasonal storage of heat, facilitating the implementation of e.g. waste heat and solar heating.

Overall, this strategy estimates that the heating sector's need for bio-based feedstock could be reduced by up to 15 TWh by 2045. However, this does not mean that the heating system will reduce the actual use of biofuel by the same amount, as much of the waste heat that will be used will come from the increasing production of biofuel. Current CHP production from biofuels with positive effects on local electricity supply is assumed to continue in the long term.

# 9. Action plan

The focus of the strategy is to show how markets and policies, including the price mechanism, contribute to making alternative solutions competitive to solve the future need for bio-based feedstock highlighted in the roadmaps. An increasing number of countries are now moving to achieve the Paris Agreement, which is likely to result in increased global demand for bio-based feedstock and hence prices. This, in turn, will steer bio-based feedstock to the sectors with the highest willingness to pay, which are likely to be those sectors where few or no fossil-free alternatives other than bio-based feedstock exist, or such alternatives have very high costs.

In several sectors, there are alternatives to using bio-based feedstocks to achieve fossil freedom. In the transport sector, electrification is expected to become the dominant “fuel” by 2045, and for much of industry, electrification and hydrogen technologies are expected to enable fossil freedom. Development in the use of biofuels in the heating sector are expected to be largely driven by price development. Thus, there may be an opportunity for alternative technologies like deep geothermal energy, solar heating and increased use of waste heat to become more cost-effective alternatives that can make up a larger share of the energy supply in 2045. However, the maturity of the technology and the conditions for implementation vary between sectors and alternatives, and can therefore have different impacts. Although development is expected to be largely market-driven, there is also a need to introduce policy instruments in certain areas to accelerate or facilitate development.

To realise the potential of bio-based feedstocks in climate change mitigation, obstacles and proposals for increasing the added value of Swedish bio-based feedstocks are presented below. However, to enable the implementation of the roadmaps, solutions in other sectors will also be crucial to free up resources for areas where other alternatives are lacking. For this reason, obstacles and proposals for increased energy and resource efficiency as well as for an increased pace of electrification in society are also highlighted.

## 9.1 Increased added value of Swedish bio-based feedstocks

### Challenges

The estimated need for biofuels in the transport sector is estimated at 30–40 TWh/year in 2030, while the total domestic production capacity today is about 5 TWh/year. Several actors are planning for increased domestic production, but this is largely dependent on imported feedstock, such as fats and oils. The world demand for biofuels is expected to grow strongly, and competition for feedstocks will thereby increase. The increased demand may also drive the use of feedstocks with greater environmental impact.

In order to increase the value of Swedish agricultural and forestry by-products, residues and energy crops, and also to ensure that a higher proportion of the biofuels used in climate change mitigation are of a high sustainability class, biofuel production based on Swedish feedstocks should increase. However, alternative biofuel production technologies that can use feedstocks from the forest industry in particular have not been competitive so far. This is largely due to high investment costs combined with the fact that the technologies are often not yet implemented on a commercial scale. In many cases, the economic risk needs to be reduced in order to scale up various technological advances.

The Swedish Energy Agency is currently investigating policy instruments to promote Swedish production of biofuels using new technologies. This could prove to be a very important piece of the puzzle in realising the potential for biofuel production from Swedish sustainable feedstocks.[36] In its report, the Phase-out Inquiry proposed, among other things, that a special quota for advanced biofuels and electrofuels be introduced in the reduction obligation.[42]

Sweden recently had its application for an extended tax exemption for highly blended liquid biofuels extended for a further year. The EU review of state aid rules is likely to allow Sweden’s exemption to remain in place in the long term. Should this not be implemented, other policy instruments for highly blended biofuels than tax exemptions from year to year are needed to make these fuels more competitive on the market.

For Swedish road transport, the pace of electrification is expected to reduce the need for biofuels significantly after 2030. At the same time, it is important to ensure sustainability and continued favourable conditions for other renewable fuel alternatives that are already available in the existing vehicle fleet and infrastructure, not least for heavy transport needs.

Global demand for biofuels is expected to increase, which will also increase the opportunities for exports of sustainable biofuels from Sweden. Nevertheless, it is important that future investments in biofuel production are flexible and can shift between or co-produce different products in varying proportions. This could include plants with the capacity to produce biofuels for road transport, biojet for aviation, or renewable feedstock for the chemical industry. Policy instruments to help bring about these plants should therefore not be limited to fuels alone, and should promote both liquid and gaseous fuels.

The chemical industry is one sector where there is unlikely to be any alternative to the use of bio-based feedstocks to achieve the target of being fossil free by 2045. The sector currently uses large quantities of fossil feedstocks, and is working on several different tracks to transition to fossil-free production. Efficiency improvements, CCU and electrification are estimated to have the potential to replace one-third of today's fossil feedstocks. Technologies based on chemical recycling of plastic waste could replace another third. This means that the last third of the fossil feedstocks used will need to be replaced with biogenic feedstocks if the industry is to achieve the target of being fossil free.

However, current policies steer bio-based feedstock to the transport sector, which means that the chemical industry, where the willingness to pay is still low, cannot compete for the feedstocks. To gradually increase the share of bio-based feedstock, one approach is to work towards developing a mass balance model. The mass balance approach is based on a certain volume of bio-based feedstock being added to the same system as the fossil feedstock. A volume of bio-based products corresponding to the volume of the bio-based feedstock input is then sold.

Renewable gas has the potential to contribute to achieving climate targets in several sectors of society, as a feedstock and energy source for industry, in vehicles and vessels, and for electricity and heating production. In Sweden, there is also domestic biogas production which, with existing technology, can be scaled up at a rapid pace if the right economic conditions are in place. At present, Swedish production of biogas is hampered by production subsidies in other countries that distort competition in favour of biogas imports as well as difficulties in competing on price with fossil alternatives in several potential sectors, not least in industry. The Biogas Inquiry (SOU 2019:63) has made proposals for national targets for Swedish biogas production and various forms of support for biogas production.[65]

Achieving the goal of climate neutrality by 2045 will require significant emission reductions combined with negative emissions. These negative emissions can be made possible through bio-CCS, where biogenic carbon dioxide is captured and stored. However, the carbon dioxide storage made possible through bio-CCS cannot be counted on as a carbon sink under the Commission's proposed revision of the LULUCF Regulation, which would facilitate Member States' ability to achieve increased carbon sink requirements. Carbon capture technology is available today, but has relatively high costs and energy consumption. Enabling negative emissions via bio-CCS will require policy instruments that technically and economically support a more large-scale implementation of the technology. The Government has announced that a system for operational support for bio-CCS in the form of reverse auctioning will be introduced by 2022, with the first payments for stored carbon dioxide planned for 2026.

**Proposals:**

1. In order to secure continued tax exemption for clean and highly blended biofuels, the Government should work to implement the European Commission's proposal to allow for this within the state aid framework (point 77 of the CEEAG). Until this change is in place, the current tax exemption should be extended. In the event that tax exemptions are not granted in the long term, one option is to include clean and highly blended biofuels in the reduction obligation.
2. The Government should stimulate the domestic production of biofuels from lignocellulose, for example

through an advanced quota in the reduction obligation, which should be possible to introduce in 2024.

3. By 2022, the Government should set the blending levels in the reduction obligation for aviation kerosene for the years 2030–2045 and work towards equivalent targets in the EU. The final target should be 100 percent blending by 2045 in both cases.
4. The Government should promote changes in the EU Air Services Regulation that allow for fossil-free air transport requirements on appropriate domestic routes procured by the state. In December 2020, the Swedish Transport Administration submitted a feasibility study on the possibilities for procurement of fossil-free flights to the Government. [66]
5. To stimulate new technologies and larger volumes of renewable gas, and to enable the necessary investments, it is important for a long-term production subsidy to be introduced as soon as possible for biogas from anaerobic digestion, proposed in line with the Biogas Market Inquiry's proposal for subsidy package 1, and for the proposal for subsidy package 2 to be fully developed through a commission to the Swedish Energy Agency on industrial use.
6. In 2022, the Government should introduce the targets for supplementary measures proposed in the Climate Policy Roadmap Inquiry's report (SOU 2020:4), where the target for bio-CCS is up to 10 million tonnes/year. [1]
7. In 2022–2023, the Government should support the development of the mass balance concept in order to increase the share of bio-based plastic in a safe, traceable and sustainable way.
8. In 2022, the Government should instruct the Swedish Forest Agency to submit proposals on how requirements for ash recycling can be introduced to minimise the environmental impact of increased branch and top removal.

## 9.2 Other areas significant to the use of bio-based feedstock

### Challenges to increasing energy and resource efficiency

Challenges to increasing energy and resource efficiency Efficient use of energy is crucial to achieving climate and energy policy goals. Energy efficiency improvements for buildings free up resources and reduce problems with local capacity and infrastructure needs to supply and produce electricity and heating. The existing systems to support the transition to fossil freedom, such as Klimatklivet and Industriklivet, largely lack an energy efficiency perspective at present. It is therefore not possible to obtain support for investments that use renewable energy more efficiently to the same extent as it is possible to obtain support for investments that aim to replace fossil energy use with fossil-free energy use. Both types of investment are important for the success of the transition to a fossil-free society.

According to the building regulations of the National Board of Housing, Building and Planning, purchased energy is currently reported instead of used energy when a building's energy performance is calculated. This means that energy generated in the building or on its site and then used by the building is not included in the building's energy use. The installation of self-generated energy can therefore be counted as an energy efficiency improvement measure, but does not necessarily mean that less energy is used.

Swedish heat production is largely bio-based and generally has high energy efficiency, especially when combined with renewable electricity production in CHP plants that contribute to plannable electricity production. It is important that these plants can be fully used for electricity production at times of peak electricity demand, which often coincides with high heat demand. Today, electricity production is sometimes not prioritised at these times for cost or capacity reasons.[55] There are opportunities to substitute biofuels for district heating with other heat sources, but the industry is sensitive to competition, and currently largely uses fuels that are difficult to use in other sectors and therefore have a lower cost.

If the competition for bio-based feedstock increases, the district heating industry will turn to less costly energy sources. However, this shift will take time as it may require the erection of new plants or the modification of existing ones. Research and development of alternative heat sources such as deep geothermal energy and solar heating are therefore required in the near future to have the potential to be a competitive alternative for heat production.

District heating networks, which exist in most Swedish cities, allow for the use of residual energy from industries. High-temperature waste heat is already widely used where the geographical and economic conditions exist. The use of waste heat is resource efficient and needs to be used to a greater extent than is currently the case. There is also increasing potential to use more low-grade heat from e.g. data centres or new processes such as hydrogen or biofuel production.

An important prerequisite for this is that these plants are located close to heat production and infrastructure so that waste heat can be utilised. One resource-efficient technology with great potential is to co-produce electricity and heat in existing bio-based CHP plants with bio-oils, which can then be further refined into biofuels.[64]

A larger proportion of waste-based district heating may mean that there is a risk of the plannable fossil-free electricity production contributed by today's CHP plants decreasing. The electricity system therefore needs to be considered as a whole when discussing alternative heat sources. For example, more flexibility in the system could be achieved by adding more heat pumps to the district heating network, which could increase the potential to use wind power during periods of low electricity prices and CHP when prices are higher.

The use of residual energy is a resource-efficient way of utilising energy, whether of biogenic or fossil origin. It may therefore be counterproductive that residual energy from fossil industries and energy from waste incineration are not currently defined as sustainable.

Waste incineration is an important contribution to today's district heating production. In this strategy, it is estimated that in 2045, waste incineration will remain at approximately the same levels as today. Reducing the amount of plastic in waste over time is a prerequisite for making this type of energy recovery more sustainable. The Swedish Environmental Protection Agency has been commissioned to submit proposals in 2021 on product groups or material flows where quota obligations for the use of recycled feedstock would be appropriate, and also to propose measures to increase the recycling of plastics in non-toxic cycles in Sweden.[67, 68]

The waste volume in society will decrease due to increased incentives for reuse and recycling. However, incineration will continue to be a good final solution when products have reached the end of their life and cannot be circulated further, and Sweden already has good conditions for dealing with waste, both from Sweden and other parts of the EU. If this incineration is also done with CCS, climate emissions can be further reduced or even become negative. In order to make use of the Swedish prerequisites for final treatment and recycling of residual waste remaining after sorting, it needs to be promoted that policy instruments for Swedish waste incineration plants compared to plants in the rest of the EU are put on an equal footing.

**Proposals:**

9. In 2022, the Government should reintroduce the state subsidy "Energisteget" [Energy Step], which in 2018–2020 supported energy efficiency improvements in industry. In the previous period, the subsidy amounted to SEK 105 million. But if reintroduced, it should be expanded and run for a longer period.
10. In 2022, the Government should commission the National Board of Housing, Building and Planning to develop building regulations that require the reporting of energy used instead of energy purchased when calculating the energy performance of a building, with the aim of steering the regulations towards more energy-efficient buildings. Incentives for self-produced energy remain important, but should be separated from energy performance regulations.
11. In 2022, the Government should commission the Swedish Energy Agency to investigate the possibilities for increased utilisation of waste heat. The assignment could, for example, include amending the Electricity Act so that conditions set for system solutions can ensure that the residual energy generated in new plants is used to the maximum, removing obstacles to the recovery of waste heat, and putting instruments in place that encourage and provide incentives for adaptations of customer plants to enable lower temperatures in district heating networks.
12. In 2021, the Government should implement the Swedish Energy Agency's proposal that low-temperature waste heat be included in the Act (2014:268) on Certain Cost-Benefit Analyses in the Energy Sector [56].

13. The Government should review and clarify that renewable and recovered energy should be treated equally in all relevant legal contexts, such as the building regulations of the National Board of Housing, Building and Planning, and in negotiations within the EU. The use of residual energy is a resource-efficient way of utilising energy, regardless of origin.
14. In 2022, the Government should commission the Swedish Energy Agency to review the possibilities of introducing incentive schemes for deep geothermal energy and solar heating in the district heating system, and develop Industriklivet to include new technologies for heat production. The assignment should also include reviewing the possibilities to support increased heat storage in the district heating system.
15. In the years 2022–2026, the Government should allocate funds for further research and technological development of alternative technologies for the heating sector, such as deep geothermal energy and solar heating.
16. In 2022, the Government should introduce a national quota obligation system with recycling certificates for plastics to boost demand for waste-based recycled plastic feedstock and increase incentives for further waste sorting. The Government should work towards a common European system in the long term.

### Challenges to increasing the pace of society's electrification

The expected increase in global demand for bio-based feedstocks will mean higher prices, which means that alternative solutions such as electrification may become more competitive. However, increased electrification will require investment in grid expansion, resources, a holistic approach, and systems thinking to realise the potential.

With increased demand for fossil-free electricity from all industries that are now in transition, coupled with the increased demand from hydrogen production, more fossil-free electricity production will be required. The majority of projections show that wind power is the type of power that achieves the lowest electricity production costs, and electricity production from wind power in Sweden is expected to increase from 36 TWh in 2021 to 50 TWh in 2025, according to the Swedish transmission system operator short-term market analysis. But after that, the development is more uncertain. The Swedish Energy Agency and the Swedish Environmental Protection Agency find it worrying that very few new permits are being issued, and many applications are being rejected or reduced in the course of the process. Faster and more predictable permitting processes are needed to get the electricity needed on time.

Sweden's well-developed district heating system fulfils an important function in an increasingly electrified society, where electricity can be used in industry or transport, for example, instead of heating buildings. The bio-strategy assumes that today's bio-based CHP production will continue to exist, but competitiveness needs to be ensured for this to happen.

For the electrification of the transport sector to take place, charging infrastructure for passenger cars, heavy-duty vehicles and vessels as well as infrastructure for hydrogen-based fuel cell vehicles must be developed at pace with electrified vehicle fleet growth. In this strategy, the market is expected to steer towards a high rate of electrification, as long as the infrastructure is expanded at pace with market growth, and a national target year for 100 percent zero emission passenger cars is therefore not considered necessary.

The Government is working to develop an electrification strategy with the aim of taking a holistic approach to the conditions in the energy sector in order to enable increased electrification. The strategy is expected to be adopted by the Government in October 2021. The Government has also appointed an Electrification Commission to accelerate work on electrification of heavy road transport and the transport sector as a whole. In consultation with relevant actors, the Commission will identify measures that can be taken to accelerate the pace of electrification in the transport sector. All forms of electrification for passenger and freight transport in all modes of transport are covered by the Commission's work.

A number of proposals to facilitate the role of electrification in the transition to a fossil-free society have previously been put forth by Fossil Free Sweden in various contexts. Some of these are repeated below and are considered to be of particular importance for the bio-strategy, supplemented by new proposals.

**Proposals:**

17. In 2022, the Government should commission the Swedish Energy Agency to develop an action plan with timetable and concrete milestones for electrification of light and heavy transport. The assignment should also include securing the infrastructure for passenger cars, heavy-duty vehicles and vessels. The action plan should include a needs analysis and proposals for measures to ensure there are charging points for heavy-duty vehicles at loading and unloading areas, in depots for overnight charging, public fast charging along major roads, and electricity supply and charging facilities at airports and ports.
18. The Climate Premium (formerly the Green Truck Premium) introduced from 7 September 2020 should be maintained as present, but, for an introductory period for electric trucks (including hydrogen-powered ones), increased to 25 percent of the purchase cost, preferably accompanied by an increased budget.
19. In 2022, the Government should commission the authorities (Swedish Energy Agency, the Swedish transmission system operator, and the Swedish Environmental Protection Agency) to draw up a national strategy for ensuring that CHP production is maintained.
20. In 2022, the Government should initiate work to modernise relevant laws and regulations for a faster and more predictable permit assessment process that contributes to a faster pace of climate change mitigation. A first step should be to implement the proposal of the Committee for Technological Innovation and Ethics (Komet) to establish a special committee to which municipalities, regions and state authorities can report regulatory obstacles that hamper experimental activities.
21. By 2022, the Government should set a planning target of 3 GW of installed electrolytic power by 2030 and at least 8 GW by 2045 to enable fossil-free development through hydrogen production and use in most sectors.

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