



Stockholm
Sustainable
Finance Centre

Financing the decarbonisation of heavy industry sectors in Sweden

12 November, 2020

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Executive summary

The Swedish parliament has voted into law that the country should reach net-zero greenhouse gas emissions by 2045. Sweden is well positioned to achieve its targets. The country's heating and electricity systems are almost exclusively fossil fuel-free already, and electrification of transport is taking off both nationally and globally. The most pressing challenge that remains for Sweden is to achieve drastic GHG emission cuts in heavy industry.

Until now, discussions of decarbonisation of heavy industry have been rather general, with many different sectors often bundled together as "heavy industry", "basic industry" or "process industry". This overlooks substantial differences between the industries in terms of the specific technological options available to each sector, product market structures, and a host of other nuances that are essential for policy-makers and investors alike to understand.

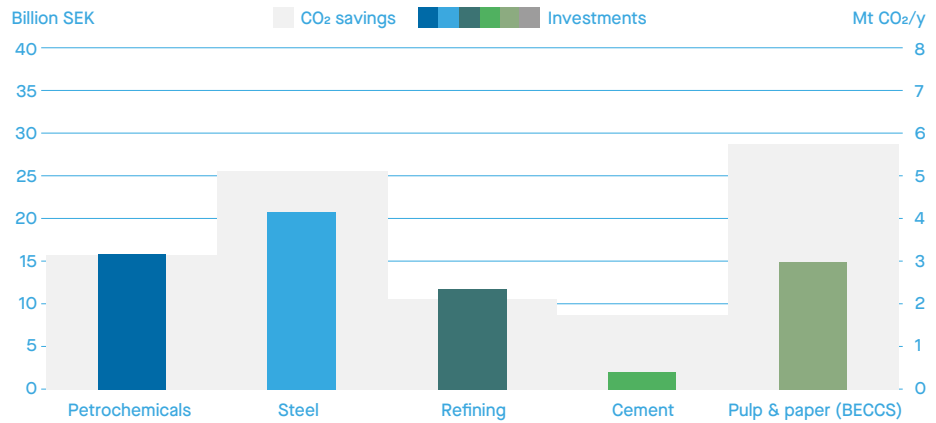
Investment needs in heavy industry

This report presents a sector-by-sector analysis of the largest CO₂-emitting industries in Sweden, which together are responsible for about 17 million tonnes (Mt) of CO₂ per year, almost one-third of Sweden's GHG emissions. In particular, it focuses on investment needs and how financing challenges differ among sectors. Heavy industry representatives have themselves highlighted financing as a potential bottleneck in roadmaps developed recently under Fossilfritt Sverige, a government initiative to support the development of roadmaps to achieve net-zero emissions in major economic sectors in Sweden. The report specifically addresses the question: **How significant is the financing challenge in the process of transitioning key Swedish industrial sectors?**

Based on a sectoral review and analysis carried out with the consultancy Material Economics, it is estimated that a net increase in investment of about **66 billion SEK (€6.5 billion)**, above those investments needed to maintain current production levels, using existing technologies, are needed to decarbonise Swedish heavy industry. Of this, 50 billion SEK would need to be invested between 2020 and 2045 to transform the four largest emission sources in Sweden, representing around 12 Mt CO₂ per year, or 70% of industrial emissions:

- 21 billion SEK for the transition of primary steel production to a process based on hydrogen direct reduction (H-DR)
- 2 billion SEK for adding carbon capture and storage (CCS) to cement production
- 16 billion SEK for converting crackers in the petrochemicals sectors to use recycled plastics as feedstock
- 12 billion SEK for conversion to electrolysis production of hydrogen and adding CCS to oil refinery operations

The remaining 30% of CO₂ emissions from heavy industry involve many relatively small sources, but still amount to 5 Mt CO₂ per year. Research suggests that the most cost-effective decarbonisation option is to use negative emissions at large biogenic point sources in the pulp and paper sector. Adding about 15 billion SEK of investments for CCS in the pulp and paper sectors achieves net-zero emissions from Swedish industry and brings the total capital needs up to 66 billion SEK (see figure below).

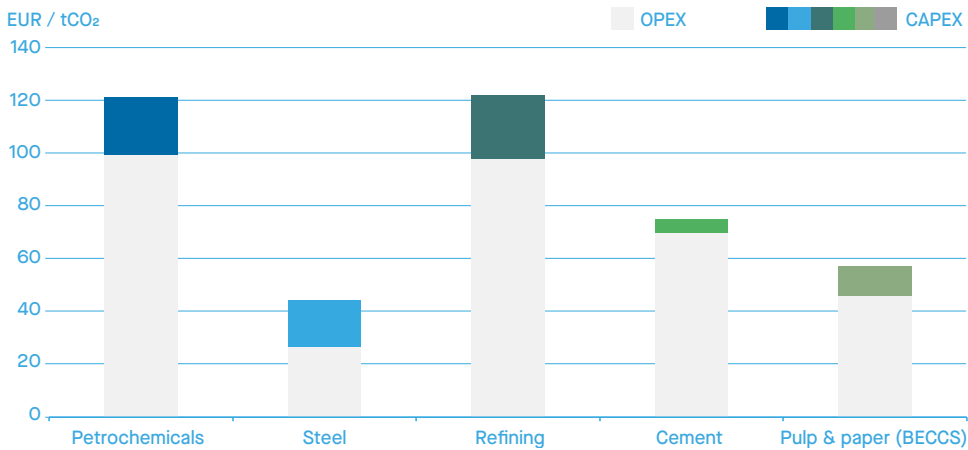


Additional sectoral investment costs 2020–2045 for achieving net-zero emissions and annual CO₂ reduction potential by sector.

Key differences in investment needs and increased operational costs

The need to make large investments in low-carbon technologies is clearly not the only challenge. This only addresses capital expenses (CAPEX). Total costs include both capital and operational expenses (OPEX), which can vary substantially among industries. The second question addressed in this report is: **To what extent do finance issues actually constitute a bottleneck in each industrial sector, compared with challenges related to increased operational expenses?**

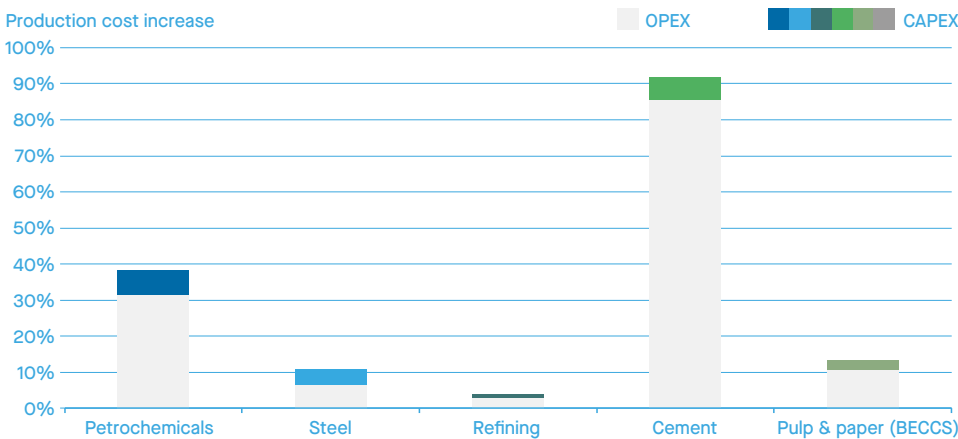
We show that the finance and capital challenges in the transition of Swedish industry to net-zero vary heavily from sector to sector. **The relative importance of the financing challenge depends largely on how much each sector's production processes need to be transformed.** Adding CCS to cement or pulp and paper plants, or to oil refineries, is not a transformative change, as the key processes themselves remain largely intact, and the investments needed are relatively small. However, adding CCS entails substantial OPEX increases that need to be covered in order to make these investments financially viable. In contrast, a transition to hydrogen produced with electrolysis, used in H-DR steel, petrochemicals and refining, entails more radical changes: to varying degrees, portions of the production process are fully replaced with low-emitting alternatives. These require larger transitional investments, and the total effects on CAPEX and OPEX vary significantly among industries (see figure below).



Capital (CAPEX) and operational (OPEX) cost contribution to total abatement cost.

Sources: Total abatement cost for each sector according to the most recent literature and CAPEX according to data in this report.

In the figure above we can see that for hydrogen direct reduction for steel production, capital expenditures represent a large share of total abatement costs (40%), while for cement, they are only 7%. However, as illustrated below, post-transition OPEX for steel could remain similar to today's, keeping total production cost increases down (+10%). For cement, the operational costs challenges are significant, leading to a near-doubling of cement production costs (+90%). With petrochemicals, costs are very dependent on changes to plastic production, collection and recycling that allow for circular material flows, with large impacts on operating costs and total production costs (+38%).



Production cost increase related to higher CAPEX and OPEX compared with typical cost in Europe.

Source: Analysis in this report.

Comparing the two figures above we see that the abatement costs per tonne of avoided CO₂ for the cement sector are just over half of those for refining and petrochemicals (75€/tCO₂) and the capital needs are the smallest. However, cement has the largest increases in operational costs. This is because of the low product value per tonne of cement compared with refining, for example, for which the abatement costs are

much higher, but the total production cost increases (+5%) are just a fraction of those for cement.

In contrast, the conversion to H-DR for steel production demands large investments, but the operation expenses of the new process are not much higher than for the current process. In fact, with favourable developments in prices of a few select commodities (electricity, coking coal and emissions credits), the H-DR process could have total costs in line with, or lower than, the current blast-furnace based process.

Although oil refining and cement differ greatly in terms of operating cost increases, the two sectors are similar in that it is OPEX, not CAPEX, that increase most, mainly due to the addition of carbon capture. This is likely to be more expensive for refining than for cement because the CO₂ emissions in a refinery are distributed across several different point sources, while a cement facility has one large point source.

Finally, the conversion to a petrochemical feedstock process based on recycled plastics will require substantial additional capital expenses in the transition. Moreover, it will also require a systemic society-wide transformation in how plastics cycle through the economy.

Comparing investment needs with the broader set of challenges that industries face

It is crucial that policy-makers take into account and address sectoral differences in terms of financing needs, conditions for ensuring demand for green industrial products, and regulatory challenges. While capital and finance issues are important for all sectors, for most sectors, other issues are as important or more important. In particular, issues related to available infrastructure in the form of high-capacity electricity supply (especially steel and oil refining) and for implementing CCS at scale (oil refining, cement, and pulp and paper) are crucial. In addition, higher operational costs will have to be covered by higher prices and a willingness of consumers to pay for decarbonisation, or else by new policy measures that generate revenue to cover the additional expenses, such as for CCS. While the EU ETS could have a role to play here in the case of cement and oil refining, negative emissions (from bioenergy with CCS, or BECCS) would not be covered, and hence would require an additional set of policy measures.

The analysis in this study shows that the costs for decarbonising heavy industry are manageable. However, it is also well known that in the absence of strong carbon pricing signals, the incentives for investing in new low-carbon production methods are low, while the risks for individual companies are high. Given that the EU ETS is slated to continue to give out free emissions allowances over the coming decade, including to the four sectors covered in this report, there is a need to complement the existing pricing system. Sizable and long-term support mechanisms are needed to accelerate the progress of these industrial sectors through large-scale demonstrations and even commercial-scale efforts.

While risk-sharing and investment support are widely seen as desirable, it is unlikely that public actors would take on a majority of the burden of financing a low-carbon transition for privately held heavy industry companies in Sweden. If the state covered half the upfront investment estimated in this report – for instance, as part of a COVID-19 recovery package – the level of capital required would be a fraction of what has been and will be invested in other types of infrastructure. For example, pre-COVID, Sweden planned to spend more than 622 billion SEK on transport infrastructure between 2018-2029, or about 60 billion SEK per year. **The capital needs to decarbonise industry through to 2045 are thus just over one-tenth of the planned transport infrastructure effort over the coming decade.**

The Swedish Government's Industriklivet programme currently makes 600 million SEK available each year for investments in decarbonising industry, a figure that will increase to SEK 750 million from 2021. As a rough initial estimate based on the figures from this study, **we suggest that doubling or tripling direct public support from current levels throughout the coming decade** would be enough to meet the financing challenge and meaningfully accelerate larger-scale efforts and put Swedish heavy industry on track to meet climate targets. At the same time, the findings of this report make it clear that finance alone will not ensure a full industrial transition. There is a need to address several sector-specific challenges related to carbon pricing, and to adopt policies that create markets for low-carbon materials.

For helpful inputs into the writing of this report we would like to thank Material Economics, Oliver Johnson, Lauri Tammiste, and Fredric Bauer.

”The intent to decarbonise is clear, but in most cases, the vision is not yet backed by investment plans laying out a path to full decarbonisation.”

Introduction

A new Climate Act came into force in Sweden in 2018, committing Sweden to achieving a target of net-zero greenhouse gas (GHG) emissions by 2045 and negative GHG emissions thereafter (Regeringskansliet 2017). Sweden has more or less decarbonised its electricity and heating sectors (Figure 1), so achieving the climate target requires a focus on three key remaining issues: decarbonising transport, decarbonising heavy industry, and achieving negative emissions¹ (Naturvårdsverket 2019; Klimatpolitiska rådet 2019).

This report focuses on solutions for decarbonising Swedish heavy industry, and the investments required to successfully implement them. Heavy industry emits about 17 million tonnes (Mt) CO₂ per year, almost one-third of Sweden’s total CO₂ emissions (Energimyndigheten 2019; Naturvårdsverket 2019). At the same time, the Swedish pulp and paper industry offers the largest potential in the country for cost-effective negative emissions (Zetterberg, Källmark, and Möllersten 2019). The government’s new climate framework is being translated into more detailed action plans (Regeringskansliet 2019), but there are still few details on what decarbonising industry actually entails in terms of new investments and support for these key sources of CO₂ emissions in Sweden.

Swedish industry already recognises the long-term need to meet emissions targets in line with the Paris Agreement. The steel (Järnkontoret 2018), cement (Cementa 2018) and refining industry (Svenska Petroleum och Biodrivmedel Institutet 2019) have developed roadmaps for how to decarbonise in line with national targets, but most say little about the magnitude of the investments needed to reach net-zero emissions by 2045. The intent to decarbonise is clear, but in most cases, the vision is not yet backed by investment plans laying out a path to full decarbonisation. This report presents investment estimates for decarbonising the highest-emitting industrial sectors in Sweden and begins to unpack the nature of the financing challenges those sectors face in Sweden as they transition to net-zero production over the coming decades.

The main barriers to decarbonisation of industrial sectors have been well known for decades. Low-carbon industrial production requires investments in new technologies and increases production costs. The business case for decarbonising is not there when existing methods produce materials at lower costs (Energimyndigheten 2019; McKinsey & Company 2018; Åhman, Nilsson, and Johansson 2017).

At the same time, decades of economic research show that the overall cost increases for climate mitigation are manageable from a societal perspective, and this is also true for carbon intensive industries. A recent study estimated the total cost of decarbonising the world’s ammonia, steel, ethylene, cement, heavy road transport, aviation and shipping sectors at 0.25–0.5% of global GDP in 2050, or US\$0.8–1.5 trillion per year through to 2050 (Energy Transitions Commission 2018). The added cost of net-zero production for manufactured consumer goods, vehicles and houses could be less than 1% for plastics, 1% for steel and 3% for cement. However, the production cost increases

¹) Negative emissions refers to technologies or practices that result in a net uptake or storage of greenhouse gases, removing them from the atmosphere. Examples include capturing and storage of CO₂ emissions from combustion of biogenic matter and direct capture of CO₂ from the air, but also land use change binding carbon in biogenic matter in the soil.

for intermediate industrial products are much higher: 50% for plastics, 20% for steel and 100% for cement (Energy Transitions Commission 2018). The economic viability of decarbonising industry is thus tightly linked to value chains, from the production of basic industrial goods, to final consumer goods (Rootzén and Johnsson 2016). Policies or other measures may be needed to ensure that there are viable business models for companies investing in low-carbon or net-zero industrial production.

Regulations putting a price on CO₂ or banning the use of fossil fuels are widely seen as the way forward (Meckling, Sterner, and Wagner 2017), but this is difficult for Sweden to do on its own. Without additional strong international agreements or regional arrangements – for instance, at the EU level – measures to internalise the costs of industrial CO₂ emissions will be undermined by international competitors, resulting in carbon leakage (Wesseling et al. 2017; Åhman, Nilsson, and Johansson 2017). In other words, industrial activity will move abroad, failing to reduce GHG emissions and hurting Sweden economically.

Moreover, while carbon pricing, through carbon taxes or emission trading systems, is becoming more common (World Bank 2019), the outlook for raising the price of CO₂ emissions for industry is unclear, both in Sweden and at the EU level. Prior to the COVID-19 pandemic, prices within the EU Emission Trading System (EU ETS) were at historically high levels, but future price trends are very uncertain and largely depend on the outcome of the crisis. Carbon-intensive heavy industries have also been exempted from significant carbon pricing in the past and projecting future CO₂ regulation is inherently difficult. This policy uncertainty elevates the risks for investments in the industrial projects needed to reach Sweden's 2045 climate goals.

Emissions from energy-intensive industries arise from the use of fossil fuels for high-temperature production processes and from chemical processes that convert fossil feedstocks into industrial products. As is the case around the world, the emissions from these industries in Sweden are tightly linked to economic output and have not declined significantly since 1990 (see Figure 1). In Sweden, emissions from the industrial use of fossil resources are concentrated in a few distinct sectors, mainly steel production, the petrochemicals sector, cement production, and the production of hydrogen used in oil refining (Garðarsdóttir et al. 2018; Energimyndigheten 2019; Karltorp et al. 2019, 2019).

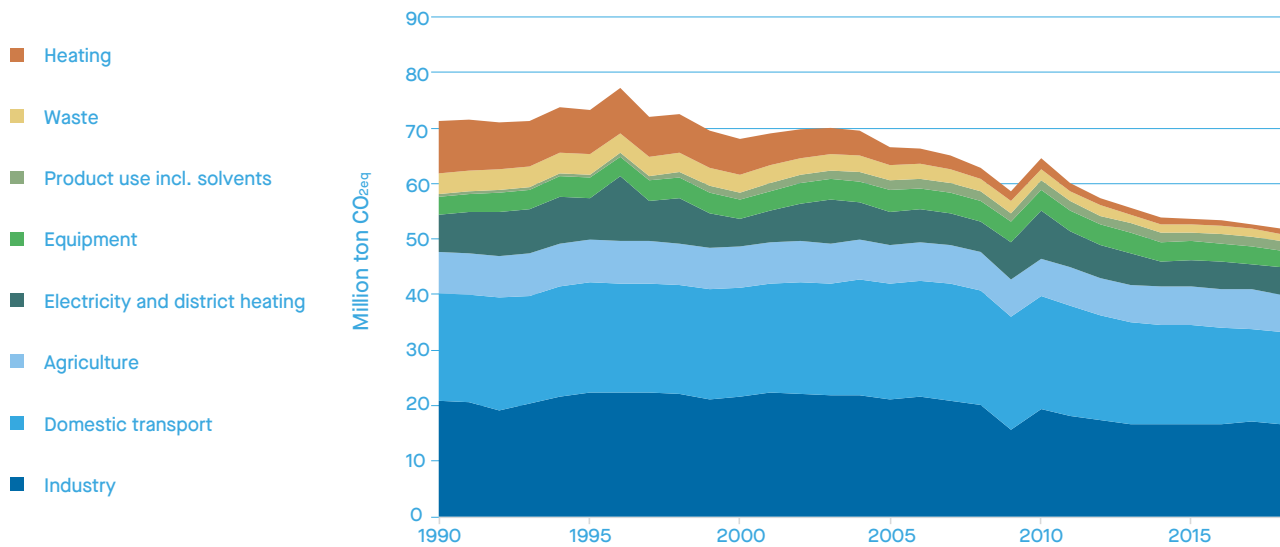


Figure 1. Sweden's territorial emissions: Total emissions are declining, but industrial emissions are not changing significantly, and industry remains a hard-to-abate sector.

Source: Swedish Environmental Protection Agency.

Industrial sectors are also closely connected to additional emissions in the economy. For this reason, it is important to understand the system boundaries adopted when analysing sectoral decarbonisation pathways. Some 2.5 Mt CO₂ equivalent (CO₂e) per year – half of the emissions from electricity production and district heating – come from the incineration of plastics for district heating.² Oil refineries in Sweden produce all the fossil fuels used in the country's transport sector, and thus all associated CO₂ emissions – and three times more emissions in other countries, because the majority of fuel refined in Sweden is actually exported.

It is clear that different system boundaries can be considered in defining emissions from industrial sectors. In this report, emissions in the transport sector are considered to be separate from industrial emissions, but the investments needed to avoid end-of life emissions for plastics incinerated in district heating plants in Sweden are considered in the analysis. The system boundaries chosen for this study reflect the technological and process changes that sectoral actors face in relation to the primary production that takes place in Sweden and that are the targets of Sweden's territorial climate goals.

The technical challenges to decarbonise are not uniform across high-emitting industry sectors (Karlton et al. 2019). Some are harder to transform than others, and the innovations required differ. More detailed assessments are thus needed of the investment challenges in each sector, and where there are similarities and differences. That is the focus of this project: understanding the conditions in each of the largest CO₂-emitting industries in Sweden and characterising their respective financial and investment challenges. In particular, this report addresses three research questions:

- What are the investment needs between 2020 and 2045 for decarbonising heavy industry in Sweden?

2) See <https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Vaxthusgaser-utslapp-fran-el-och-fjarrvarme/?visuallyDisabl edSeries=84b9611bbd3ab573>

- How significant is the financing challenge – and specifically, how important is the capital challenge compared with higher operational costs?
- How do financing challenges fit into the mix of challenges related to technology development, carbon pricing, markets for green production, infrastructure, and other system conditions?

Transition challenges for capital-intensive industrial production

Eliminating emissions from heavy industry requires not only new fuels or energy technologies or feedstocks, but major changes in production processes, equipment and infrastructure (Åhman, Nilsson, and Johansson 2017). The new technology might require inherently more capital in the same way that renewable electricity is more capital-intensive than traditional thermal electricity production with high fuel costs (T. S. Schmidt 2014). There might also be periods where elevated working capital is required, as investments in new technologies have to overlap with existing production processes while new solutions are tested (Energimyndigheten 2019; Material Economics 2019).

Industrial production plants also have long lifespans and very long investment cycles, and low-carbon transitions thus entail the problem of writing off assets prematurely, which can be a further barrier to decarbonisation. In addition, effectively implementing zero- or low-carbon processes can require changes to supporting infrastructure, such as upgrading power grids, supplying new energy carriers such as hydrogen, or building entirely new infrastructure for CO₂ transport and storage. All of this, too, increases capital needs.

Those factors pose substantial financial challenges as capital-intensive heavy industry sectors have become even more sensitive to capital expenditure and to the cost of securing this capital. Most of those investments need to be initiated by individual companies and go on their balance sheets. In Sweden, the list of companies covering the largest sources of industrial emissions is very small. Just four companies are largely responsible for about 12 Mt CO₂ per year, about 23% of Sweden's territorial emissions in 2018: SSAB (steel), Heidelberg Cement (cement), Borealis (petrochemicals), and Preem (refining).³

While capital expenditure, and the cost of capital per se, is a natural part of the assessment of the total cost of decarbonising the electricity sector (Hirth and Steckel 2016; Bachner, Mayer, and Steininger 2019; Egli, Steffen, and Schmidt 2018), there are not many analyses of the investment and financing challenges associated with a low-carbon industrial transition in Sweden. A recent assessment of the overall challenges of decarbonising heavy industry, Karltorp et al. (2019), discussed financial challenges, and in general it is recognised that different types of risk elevate capital costs or limit access to capital (Energimyndigheten 2019). Other recent studies have analysed investment costs for CCS in Sweden (Rootzén and Johnsson 2015; Garðarsdóttir et al. 2018; Onarheim et al. 2017), but with limited detail

³) Data based on IVA(2019) and annual reports of each company.

on the associated investment and financing barriers the industry sectors may face. In addition, recent technological developments that provide alternatives to CCS for the steel sector, including hydrogen direct reduction (Vogl, Åhman, and Nilsson 2018a), and advances in electrolysis that enable cost-effective production of hydrogen from renewable electricity (Glenk and Reichelstein 2019), require fresh assessments of investment needs across Swedish industry.

In general, low-carbon investments become less risky as technology improves, investment costs decline, and climate policy becomes more stringent. It has been shown that in the electricity sector, the risk reduction effect on the cost of capital is underestimated (Bachner, Mayer, and Steininger 2019). Similarly, the cost reduction potential of renewable energy (Creutzig et al. 2017) and electrification of transport (Nykqvist and Nilsson 2015) has tended to be significantly underestimated, as we have witnessed rapid learning curves for many carbon-neutral technologies (Schmidt et al. 2017; Junginger and Louwen 2019), including learning effects on financing per se that reduce costs (Egli, Steffen, and Schmidt 2018).

However, for early investments in transitioning heavy industry, the outlook for technology costs and policy developments is not yet clear, and higher risk must be accommodated in capital-intensive projects. Both the finance sector and Swedish industry have called for risk-sharing between the private and public sectors (Fossil Fritt Sverige 2018; Naturvårdsverket 2019). First, however, it is important to better understand the investment needs and business case conditions in specific industrial sectors. The aim of this report is to contribute to addressing these questions in the Swedish context and help set the stage for further dialogue on net-zero industrial policy in Sweden.

Methodology

We explore investment needs to enable fossil fuel-free production in steel, cement, petrochemicals and the refining industry, as well as investment needs in BECCS to help Swedish industry achieve net-zero emissions by 2045. We focus on the largest point sources of emissions from industrial plants in Sweden, which are owned by a few major companies. However, our estimates of investment needs are not specific to those companies, but rather generic, based on international and aggregated data. The final results on investment needs are thus broadly representative of each sector and should not be viewed as data points on the investment needs for individual companies.

We calculated costs for specific fossil fuel-free technologies in each industry, focusing on recently expressed technology choices in the Fossil Free Sweden roadmaps and public statements on plants and strategies by Swedish industry actors, when available. Calculations of capital costs, in terms of both the cost of new fossil fuel-free technologies and of renewing fossil assets, were carried out in collaboration with Material Economics and took as a starting point the analysis from the report Industrial Transformation 2050 – Pathways to Net-Zero Emissions from EU Heavy Industry (Material Economics

2019). The sources for technology costs were industry reports, academic publications, and personal communications with industry representatives. A list of key assumptions and sources for each sector is provided below. Results on investment needs were compared with recent scientific literature evaluating investment cost for CCS technology in Sweden (Garðarsdóttir et al. 2018; Budinis et al. 2018; Onarheim et al. 2017), fossil fuel-free steelmaking (Vogl, Åhman, and Nilsson 2018), and fossil fuel-free chemical production using waste plastics (Thunman et al. 2019). All figures have some uncertainty, stemming both from uncertainties about the cost of carbon-neutral technologies per se, and from the assumptions on annual production volumes. For this study we assumed that production capacity will be the same as pre-COVID production levels.

Once the investments needed to replace industrial assets have been calculated, we then derive net investments by subtracting the reinvestments that would otherwise be needed to maintain the old fossil assets. In the case of CCS, we always assume that this is a net extra cost, adding to the cost of maintaining existing assets. A general remark regarding total net investment costs is that we only include the dedicated investments in commercial production capacity. Significant amounts of money are already spent on research and R&D in these sectors, and these costs are not included. As a concrete example, the cost of the HYBRIT pilot plants currently being built is not included (see Olsson and Nykvist 2020 for a detailed analysis of pilot and demonstration plants in the transition to fossil fuel-free steelmaking in Sweden). In general, the value chains for each industry will have additional CAPEX during the transition. The analysis depends on which system boundary is drawn around each industry, and we discuss a few such issues below. As a result, the full investment needs are expected to be larger, but our analysis focuses on direct investments in large-scale production capacity for each industry.

Technological choices

Until very recently, analyses of the decarbonisation of heavy industry focused primarily, if not exclusively, on CCS. For example, CSS has long been seen as the main option to remove emissions from primary steel production⁴ (Garðarsdóttir et al. 2018; Mandova et al. 2019). However, given recent advances in hydrogen direct reduction technology, it is now clear that the CO₂ emissions from primary steel production in Sweden will be eliminated using hydrogen technology. The key determinant for this choice is that electrolysis using renewable energy is expected to become the more cost-effective solution (Åhman et al. 2018; HYBRIT 2018; Vogl, Åhman, and Nilsson 2018).

In general, the choice between CCS and decarbonisation with renewable hydrogen was a key differentiator between technological pathways considered in several sectors. For example, the refining sector in Sweden is actively testing and evaluating both options.⁵ We chose to assess the cost of transitioning to hydrogen production from electrolysis instead of CCS whenever possible, as it shows much higher potential for long-term cost reductions (Glenk and Reichelstein 2019).

4) Primary steel is produced from iron ore, whereas secondary steel is produced from recycled scrap.

5) See <https://www.preem.se/foretag/kundhos-preem/hallbart-foretagande/har-ska-koldioxid-fangas-in/>

We therefore based our investment needs estimates on renewable hydrogen from electrolysis for both the refining and plastics sectors, despite higher capital costs compared with traditional steam methane reforming with CCS.

Steel

Production of steel from iron ore with coking coal is replaced with a process that reduces iron ore with hydrogen direct reduction technology (Vogl, Åhman, and Nilsson 2018). Emissions are thus almost entirely avoided, as coking coal is replaced with hydrogen produced with renewable electricity. Calculations are based on current Swedish steel production at SSAB of 3.8 million tonnes per year (SSAB 2019), the process efficiencies and needed materials in hydrogen direct reduction (Vogl, Åhman, and Nilsson 2018), capital cost estimates for hydrogen production from electrolysis taken from recent development of large-scale alkaline technology of around US\$450/kW (NEL 2020), capital costs for electric arc furnaces of €184/tonne and direct reduction plants of €230/tonne from Vogl et al. (2018), resulting in a total capital cost of €600/tonne steel. This gives a total investment cost of about 30 billion SEK and a net investment of 21 billion SEK. Finally, a total abatement cost for hydrogen direct reduction of €44/t CO₂ is assumed, based on average estimates of Vogl et al. (2018) and Material Economics (2019).

Cement

The current production process is retrofitted with CCS, removing the CO₂ with oxyfuel CCS technology. Capital cost data are taken from the recent feasibility study by Vattenfall and Cementa (Wilhelmsson et al. 2018), drawing on research by IEAGHG (2013), which is notably lower than those in recent academic research (Garðarsdóttir et al. 2018). Investments are compared with total abatement costs of €60/tonne (Material Economics 2019), and all investments are additional to the current processes.

Refining

The production of refined petroleum products from the two largest refineries in Sweden are considered, representing around 80% of emissions from this sector. Emissions stemming from hydrogen production are removed by converting the process of steam methane reforming (SMR) using natural gas to a process where hydrogen is produced from electrolysis powered by renewable electricity. A number of smaller streams are removed with CCS. The total amount of emissions avoided from these smaller streams is greater than the emissions avoided from adopting a new method of hydrogen production. We do not consider any biofuels production, as this is closely linked to transport CO₂ emissions, not industrial emissions. Hydrogen production costs are based on estimates of near-term hydrogen production costs of €3/kg from Glenk and Reichelstein (2019) and SMR production costs based on Swedish natural gas prices,⁶ compared with international

costs (IEAGHG 2017), in line with the assumptions used in the steel case by Vogl et al. (2018). Remaining CO₂ sources from refining are harder to capture due to the many small flows and varying concentrations; we use a conservative industry estimate of €175/t CO₂ (Concave 2018), which is higher than marginal costs for additional abatement when only considering larger flows (e.g. > 500 kt/year), but with an average emission abatement cost of €121/t CO₂, in line with recent research (Garðarsdóttir et al. 2018).

The total investment costs are 12 billion SEK, and this conservatively does not consider any major investment in a new SMR plant, as it is unclear what investments are needed to maintain today's production volume. If a completely new SMR plant is needed before 2045, the investment would be around 2.4 billion SEK, based on investment cost data from IEAGHG (2017); that would reduce the net investments needed by a corresponding amount. All CCS investments are considered additional (Concave 2018).

Petrochemicals

The production of olefins from cracking of virgin fossil feedstocks is replaced with a process that chemically recycles used plastics (Thunman et al. 2019). Emission reductions from this new production method consist of avoided process emissions and avoided end-of-life emissions from plastics. Calculations are based on current Swedish olefins production capacity of 800 kt per year (Borealis 2018), the process efficiencies and material flows in a chemical recycling plant (Material Economics 2019), capital cost estimates of a gasifying plant producing methanol from recycled plastics of €900/t methanol (W2C 2018), hydrogen production used in the chemical process produced from electrolysis using renewable electricity (see steel and refining sector description), and olefins production from methanol of €300/t olefins (Dechema 2017).

This gives total investment costs, not including shipment costs, of 24 billion SEK, in line with more detailed assessments by Thunman et al. (2019). Since the new process fully replaces the old cracking of raw oil, new investments in a cracker for fossil fuels are avoided. The investment cost of a fossil fuel cracker is about one-third of the cost of a new system (Material Economics 2019), so the resulting net investment cost is 16 billion SEK. Finally, a total abatement cost for a chemical recycling process of €120/t CO₂ is assumed (Material Economics 2019).

Results

Investment needed and emission reduction potential

We first address the total upfront investments needed between 2020 and 2045 to decarbonise Swedish heavy industry. We find the total net capital costs are about 66 billion SEK. Of this 66 billion SEK, 50 billion is invested in decarbonising the largest CO₂ point sources, which would eliminate roughly 12 Mt CO₂ of the total 17 Mt CO₂ in annual emissions from Swedish heavy industry (Figure 2):

- 16 billion SEK in the petrochemical industry, building a chemical recycling system that mitigates all emissions from plastics manufacturing and recycling in Sweden, as well as emissions from the incineration of plastics;
- 21 billion SEK in the steel industry, deploying hydrogen steelmaking, mitigating 80% of all emissions from the sector;
- 12 billion SEK in the refining sector, including 2.5 billion SEK for hydrogen production and the rest for CCS mitigating 70% of emissions from the sector; and
- 2 billion SEK for cement production using CCS, mitigating 80% of emissions from the sector.

All these estimates represent net additional investments beyond what is already needed and planned in terms of reinvestment to sustain current fossil fuel-based production. It should also be noted that the emissions from refining occur as process emissions from producing fuels for the transport sector from crude oil (and natural gas for hydrogen). Eliminating the use of fossil fuels in the transport sector would obviously be an alternative path to emission reductions for this sector, but the



costs for that option are not analysed in this study.

Figure 2. Additional investment costs and annual CO₂ reduction potential of a heavy industry transition in Sweden, 2020–2045.

We do not consider it feasible to decarbonise each individual sector 100% at each point source. In general, achieving net negative emissions beyond 2045 for Sweden requires significant negative emissions (Naturvårdsverket 2019). In our analysis it is clear that the last fraction of each CO₂ stream is inherently more costly, and the economic alternative is to compensate with negative emissions to reach net-zero. Sweden has a large potential for this, as it produces 50 Mt CO₂ in emissions from major point sources, of which 65%, or 32 Mt CO₂, are from biogenic sources. In our analysis, we only utilise a small share of the total available negative emission reduction potential. Most recently, Garðarsdóttir et al. (2018) analysed cost-optimal solutions to decarbonise industry and clearly showed that large-scale CCS in

the pulp industry is more cost-effective than mitigating all smaller-scale emissions (e.g. in the minerals sector, beyond large steel blast furnaces). Zetterberg et al. (2019) arrived at similar conclusions in considering Sweden's total territorial emissions. An investment of around 15 billion SEK in the four largest pulp plants in Sweden's forestry sector would enable negative emissions of more than 5 Mt CO₂ per year (Figure 2), bringing the total avoided Swedish emissions to the 17 Mt CO₂ per year (Figure 2). The total direct investments of 66 billion SEK in production processes needed to decarbonise heavy industry amount to about 2.6 billion per year in the period 2020–2045.

The capital intensity of a low-carbon transition varies considerably across the industries we analysed. The highest reduction potential per invested Swedish krona is achieved in the cement industry (Figure 3). In general, from a climate perspective, direct public investment and support for decarbonising industry is potentially very cost-effective compared with other infrastructure projects. The individual sector investments are smaller or comparable with typical large-scale infrastructure projects and enable very large emission reductions. For example, total additional investment needs for decarbonising Swedish industry in the 2020–2045 transition phase are much lower than the total Swedish state transport infrastructure budget for 2018–2029. Current transport infrastructure spending plans exceed 622 billion SEK, or about 60 billion SEK per year.⁷ Capital needs through to 2045 to decarbonise industry are thus **roughly one-tenth of the total planned transport infrastructure effort** over the coming decade. However, comparing public transport investments with industry obviously misses the multifaceted reasons why public investments are made in different sectors. Clearly it is equally important to reduce emissions from the transport sector. However, industrial decarbonisation is vastly more capital-efficient from a mitigation perspective, so it is critically important to analyse it further.

How significant is the financing challenge?

When assessing the cost of low-carbon production options, the two main categories of costs are 1) the investments needed to build new production facilities, retrofit and upgrade existing facilities, and/or purchase new equipment, and 2) the difference between the day-to-day operating costs of existing production processes and new low-carbon processes – for instance, the difference in the cost of fuel, materials (feedstock), electricity, salaries, taxes, etc. The first category is called capital expenses (CAPEX), and the second, operating expenses (OPEX).

In this section we compare CAPEX and OPEX costs for adopting low-carbon pathways in each industrial sector. The aim of this comparison is to assess how sensitive each sector is to capital expenses per se and to highlight some of the key economic and policy barriers with financial implications. In particular, comparing CAPEX with OPEX allows us to explore the fundamental conditions under which there are viable business cases for fossil fuel-free industrial products.

7) See <https://www.regeringen.se/pressmeddelanden/2018/06/regeringens-plan-for-infrastrukturen---sa-bygger-vi-sverige-starkt-och-hallbart/>

CAPEX compared with OPEX challenges across sectors

The main long-term barrier to decarbonisation for carbon-intensive industrial production is simply total added cost and lack of a business case (Energy Transitions Commission 2018). In general, the total abatement cost per tonne CO₂ for European industry ranges between €50 and €130 (Garðarsdóttir et al. 2018; Material Economics 2019; Vogl, Åhman, and Nilsson 2018; Thunman et al. 2019; Onarheim et al. 2017). To calculate the CAPEX portion of this total abatement cost on a per year basis, we apply a 22-year lifetime to all process and manufacturing equipment (Garðarsdóttir et al. 2018).⁸ With estimates of total abatement and production costs, we can compare the relative roles of CAPEX and OPEX. As shown in Figures 4 and Figure 5, increased OPEX dominates the total cost of industrial decarbonisation in each sector analysed. Importantly, uncertainty in long-term abatement costs remains high, which is very problematic from an investment perspective.

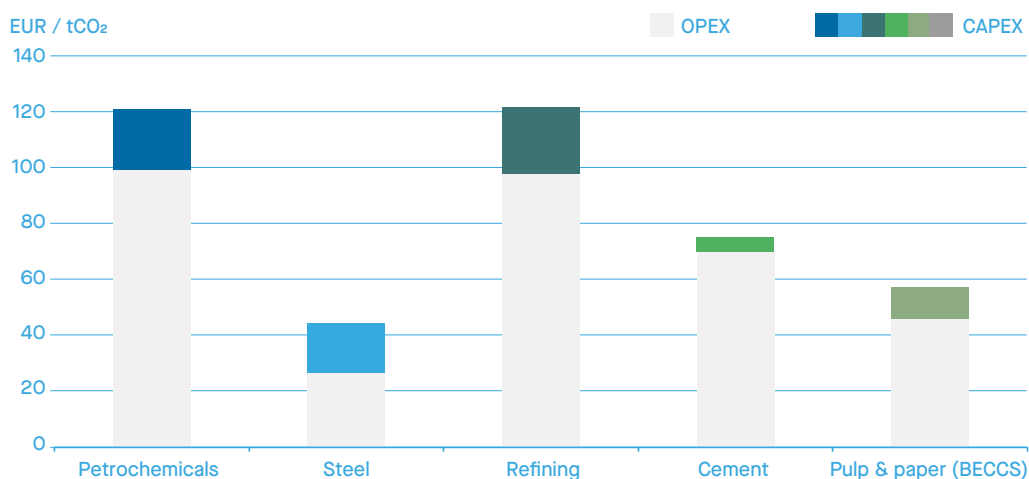


Figure 4. Contribution of capital (CAPEX) and operational (OPEX) costs to total abatement cost. Sources: Total abatement cost for each sector according to the most recent literature and CAPEX according to data in this report.

Figure 5 shows the impact of the abatement costs in Figure 4 on the cost to consumers of industrial products in each sector. These price increases for consumers are shown in terms of percent increases in production costs. The variation in production cost increases between sectors is noteworthy. It reflects both variations in the magnitude of abatement costs and the value (i.e. price) per tonne of product made by each sector. The low value of cement, just about €50 per tonne (see Table 2), combined with high abatement costs to address all the embedded emissions in a tonne of cement, explain the large product cost increase. At the other end of the spectrum, the process emissions in refining only remove part of the total carbon content of the original crude oil, as the majority is emitted in the transport sector. This fact, combined with a higher product value per tonne, means that the added cost per tonne is very small, even though abatement costs for refining are about double those for cement.

8) This figure is a typical depreciation rate for these sectors and is assessed based on 2018 annual reports from SSAB, Heidelberg Cement, Borealis, Preem and Södra. Note that green field investments with preparation of land and construction of buildings have longer lifetimes and thus slower depreciation rates. However, the transformation to decarbonised technologies involves equipment and machinery with shorter lifetimes.

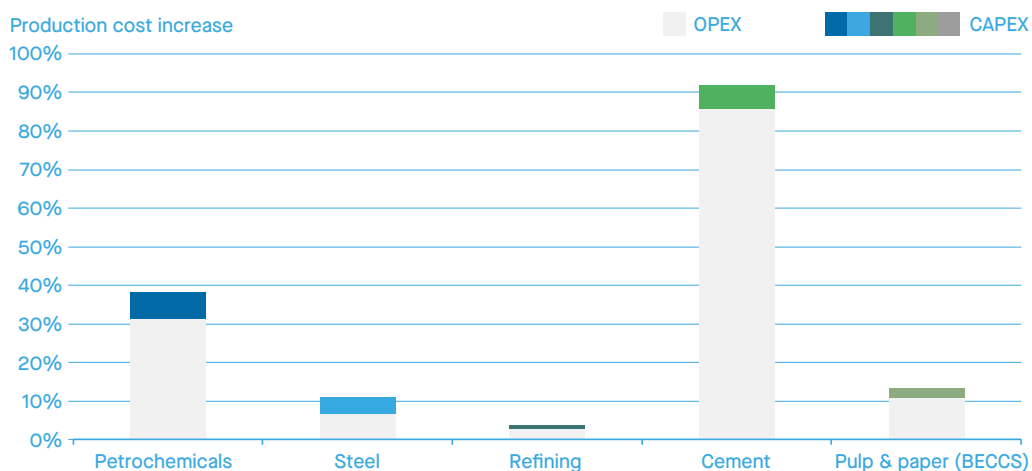


Figure 5. Production cost increase related to higher CAPEX and OPEX compared to typical cost in Europe. Source: Analysis in this report.

Steel has the lowest overall abatement costs and low added product costs, thanks to significant recent progress and potential for using hydrogen in steel production (Vogl, Åhman, and Nilsson 2018; Material Economics 2019; Åhman et al. 2018). The cement sector is at the other end of the spectrum, with particularly high added operational costs. This is due to the combined cost of electrification to replace fossil fuels, and CCS on process emissions. This technology pathway thus has rather low capital costs, but high OPEX costs for additional electricity use (Material Economics 2019).

For all sectors that depend on CCS, transport and storage of the captured carbon represent a large share of capital cost (Kjärstad et al. 2016), and this is not shown in Figure 4. However, as transport and storage cost are small compared with capture cost and as there are no plans for CO₂ storage in Sweden, this does not influence results significantly. From the perspective of Swedish industry, transport and storage of CO₂ to Norwegian storage sites in the North Sea, for example, is currently OPEX and does not add to capital requirements.

”CAPEX challenges can vary among sectors, even if they are using the same technology, due to differences in the larger systems to which the new infrastructure is connected.”

To what extent are capital needs an obstacle to low-carbon transition?

There are varying temporary finance challenges related to costs associated with transitioning from high- to low-carbon production processes. For example, companies may need to maintain both their old and new production systems over a period of time, or some of their carbon-intensive assets may need to be decommissioned before the end of their planned productive lifespan – so-called “stranded asset” risks. Based on recent annual reports, we have concluded that the industries we analysed have roughly similar facility and manufacturing equipment lifetimes, but it also matters whether future CAPEX is needed only for new low-carbon facilities and equipment, or also for retrofitting and upgrading existing production facilities and technology. In the latter case, the risk of being locked into previous capital-intensive investments assets in carbon-based production processes is higher.

In addition, CAPEX challenges can vary among sectors, even if they are using the same technology, due to differences in the larger systems to which the new infrastructure is connected. For example, cement has a single large stream of CO₂ that facilitates the use of CCS. But carbon capture technology is harder to apply in more complex manufacturing processes, such as refining or petrochemicals, which have many different streams of CO₂ of varying concentrations from a range of different process steps and production assets (Garðarsdóttir et al. 2018). This makes CCS a more complicated investment problem in refining and petrochemicals compared with cement.

Table 1 brings together the analysis of investment needs with assessments of the lifetimes of existing assets and indirect CAPEX challenges. We find that CAPEX is likely a more significant challenge in steel and petrochemicals than in cement and refining. Although the investment needs in refining are also large, the OPEX challenge dominates because most of the same processes remain in the low-carbon case, meaning that CAPEX costs for the transition are limited. For cement, additional OPEX (on top of existing production costs) for abatement far exceed CAPEX costs.

Table 1. Quantitative and qualitative summary of the importance of the CAPEX challenge across four industries

Economic barrier driven by CAPEX challenge	Petrochemicals	Steel	Refining	Cement
Share of abatement cost that is CAPEX	18%	40%	20%	7%
Product cost increase due to CAPEX	7%	4%	1%	6%
Product cost increase due to OPEX	31%	7%	3%	86%
Is CAPEX a major cost challenge in the transition to low-carbon technology?	Yes. Large in absolute terms and adds significantly to product cost.	Yes. Modest increase in product cost, but significant shift to more CAPEX-intensive technology.	No. Rather limited increase in cost of product, with a very small CAPEX challenge. Limited finance challenge per se.	No. OPEX dominates. Product cost increase primarily due to higher OPEX.
Transition finance challenge and stranded assets	Very important. Timing of investments relative to current investment cycles is key. Technology shift to new chemical recycling value chain, with many old assets decommissioned.	Very important. Timing of investment relative to current investment cycles is key. Technology shift to new hydrogen value chain, with many old assets decommissioned.	Somewhat important Asset lifetime of 10–30 years. CAPEX for hydrogen production replaces existing CAPEX. However, majority of CAPEX is for CCS, which is additional to existing CAPEX.	Not critical. CAPEX is for CCS, which is additional. Very limited phase-out of existing assets.
Indirect CAPEX challenge in larger system dependencies	Yes. New infrastructure for recycling system, and some new hydrogen technology in refining part of new recycling plant.	Yes. Significant electricity infrastructure, new hydrogen technology.	Some. Multiple CO ₂ streams with varying concentrations.	No. Single process produces 90% of emissions, with a highly concentrated CO ₂ stream.
Summary:	CAPEX important	CAPEX important	OPEX dominates	OPEX dominates

Impact of a higher CO₂ price

Another important factor in the financial viability of industrial transitions is the impact of carbon pricing. A price on CO₂ that is similar to the abatement costs for a sector will incentivise investments in low-carbon production, and if other producers are exposed to the same CO₂ price, abatement costs can be transferred to end-consumers in the value chain. However, if producers outside the jurisdiction face a significantly lower CO₂ price, or none at all, there is a risk that both domestic and international consumers of industrial products will buy from them. The

risk of such “carbon leakage” depends on how international the market for each in product is. A key factor here is production cost relative to transport cost for industrial bulk products (see Table 2). Currently, 90% of products from Sweden’s petrochemical sector, 85% from steel, and 75% of refined fuels are exported (Karltorp et al. 2019). In contrast, cement is predominantly produced and consumed domestically with only 15% exported.

Transport costs for a hypothetical long-distance (4500 nautical miles) shipping of bulk goods or refined fuels are about €15–20 per tonne, at today’s bunker fuel cost for ships (Lindstad and Eskeland 2015). For shorter trips, bulk ship transport can cost less than €10 per tonne.⁹ Figure 6 shows that petrochemical production is most sensitive to carbon leakage, closely followed by steel and refined products. A low transport cost relative to total production costs indicates a high-value product that is not costly to transport to new markets. Consequently, the risk that tougher climate regulations cause production to close down and move elsewhere is higher in these cases.

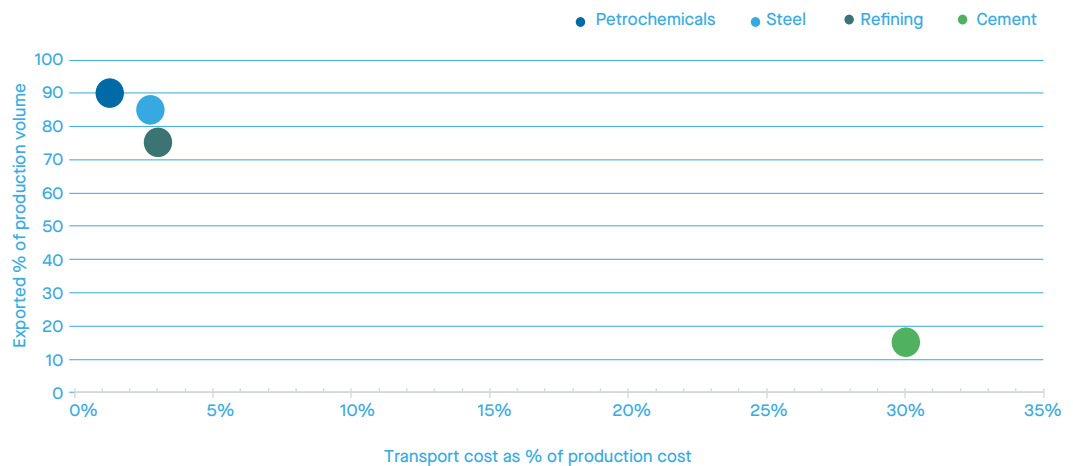


Figure 6. Illustrative transport cost of €15/t as a percentage of production cost, showing that carbon leakage is less likely in cement and most problematic for petrochemicals. Sources: Analysis in this report.

There is also a large difference to consider between making a product with the same process, but with additional equipment and costs to mitigate emissions, and using new processes with new technologies. Cement (with CCS added) is typical of the first case; steel is a prime example of shifting to a fundamentally new technology. The larger the technology shift in each sector, the greater the possibility for learning and future cost reductions in a new process that could eventually become competitive with carbon-intensive producers. However, in cases where the low-carbon technology fundamentally adds cost on top of the same process, there is no prospect for ever becoming a cheaper option than the original high-carbon process. The result is that industries that cannot reshape their production processes are highly sensitive to CO₂ price mechanisms due to the prospect of competition from jurisdictions or sectors with low or no carbon prices.

9) See <https://www.argusmedia.com/-/media/Files/sample-reports/argus-freight.ashx?la=en&hash=73FA0EB97E8928B9F5772BAC94DE91F25D30509C>

Table 2. Potential impact of higher CO₂ prices on investments across industries

Impact of CO ₂ price	Petrochemicals	Steel	Refining	Cement
Abatement cost of assessed technology	>€100/t CO ₂	€45/t CO ₂	>€100/t CO ₂	€75/t CO ₂
Typical production cost	€1200/t	€550/t	€500/t	€50/t
Production cost increase	High: 38%	Moderate: 11%	Low: 4%	Very high: 92%
International transport cost	€10–20/t	€10–20/t	€10–20/t	€10–20/t
Significance of carbon leakage risk due to global market and transport cost	Very high risk for carbon leakage. Very high share of goods traded and very low transport cost relative to product cost increase.	High risk for carbon leakage. High share of steel is traded. However, focus on highly refined steel grades and products as opposed to bulk steel mitigates leakage risk to some degree.	High risk for carbon leakage. Very high share of refined products traded. Transport cost low compared to product cost increase.	Lower risk. Transport cost on the same order of magnitude as product cost and cost increase. Higher incentives for investments.
Is the process technology new, and is there a business case for it?	Partly. Recycling system is an entirely new business case, but it adds cost and is for now inherently more expensive. Future development is very uncertain.	Yes. Hydrogen technology assessed is new technology. Higher incentives for investments.	Partly. CCS primary technology and simply adds cost, but some hydrogen tech replacing assets.	No. Industry product and its emissions tied to process. CCS simply adds costs.
Summary:	Unclear how CO₂ price mechanism drives investments. Abatement cost are high, with large impact on product cost and risk of carbon leakage. Policy intervention required, e.g. ban on plastics incineration, or CO ₂ pricing.	Higher CO₂ price drives investments. Abatement costs are moderate and production cost increase potentially limited, so there is likely a business case.	Unclear how CO₂ price mechanism drives investments. High carbon leakage risk, high abatement cost but low production cost increase. Instead, major investments hinge on policy choices on biofuels.	Higher CO₂ price drives investments. Abatement cost are high, very high impact on production cost, but limited carbon leakage can drive investments.

Finally, in Figure 7, we connect the analysis in Table 1 of the relative importance of CAPEX vs. OPEX with the analysis of sensitivity to CO₂ pricing in Table 2. The transition in all sectors depends at least somewhat on a CO₂ price mechanism, and all sectors face important capital challenges, but this figure shows the relative importance to each of the four sectors. It is clear that they face very different financing challenges to decarbonise.

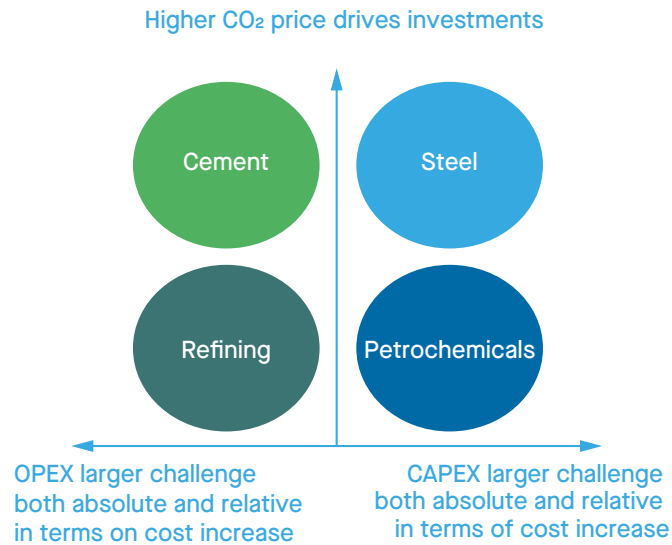


Figure 7. Relative importance of CAPEX vs. OPEX and varying incentives for investment given higher CO₂ price.

How should we understand the financial challenge?

For hard-to-abate industrial sectors, technological, institutional, infrastructural, market and policy barriers are deeply intertwined with questions about financing. Thus, financing challenges should be understood as involving a range of issues that affect the economic viability of investments. Several analyses of some key financing and investment barriers (Brown and Granoff 2018; Polzin 2017; G20 2018) have highlighted mismatches between the scale and time horizons of risk-willing capital and the investment needs of industry, weak carbon pricing or carbon leakage risks, regulatory and policy uncertainty, and a lack of data and technical know-how among financiers about low-carbon pathways.

Uncertainty over policy directions is a key concern. There are still significant disconnects between overall EU and Swedish climate targets and tangible policies. Sweden and the EU have been clear about their goals to decarbonise by 2045 and 2050, respectively, but current carbon prices – around €25 per tonne CO₂ just prior to the COVID-19 crisis – are incompatible with those long-term goals. Indeed, they are half to one-fifth of the abatement costs for the sectors assessed in this report (see Figure 4). Moreover, for Phase 4 of the EU ETS, which extends to 2030, some 90% of industrial emissions will still be covered by free emissions allocations (Zetterberg, Källmark, and Möllersten 2019).

Differences in the investment and financing challenges across Swedish process industries

The analysis conducted so far shows that the technological and economic conditions for decarbonisation vary across industries – and financial challenges should be expected to vary as well. Below we summarise the main conclusion to draw for each industry and map some of the financial barriers typically discussed in the literature on each sector.

Steel

Converting Sweden's blast furnace-based steel production to a low-carbon solution requires very large investments in hydrogen production capacity, new iron reduction and steelmaking technology. At the same time, the move to carbon-free steel with hydrogen adds fairly limited extra costs per tonne of steel produced. Technology cost reductions can be expected, and with low-cost renewable electricity, hydrogen direct reduction has the potential to be a breakthrough solution, with competitive costs in the long term. The high momentum globally on hydrogen steelmaking indicates that the risk-reward profile for these investments is improving.

For steelmakers, the financial challenge can be summarised as added capital cost with overlapping production processes, and the challenge of securing financing for costly demonstration plants. A clear financial challenge from an investor's point of view will be understanding the gradually lower risk of this new low-carbon technology in relation to the growing stranded asset risks associated with older, carbon-intensive production facilities. In summary, the capital requirements are high, but the business case is improving, making the financial challenges relatively manageable.

Cement

For cement, the financial challenges are very limited, in that the added operational costs far exceed capital costs. In addition, given current levels of technological development, only two ways forward appear scalable over the coming decade: capture CO₂ with CCS technology, or limit production of cement from limestone, utilising existing materials in a more circular economy (Material Economics 2019). CCS technology applied to cement is thus in a very similar situation as CCS applied to coal power – CCS will always add cost relative to the current process (Nykvist 2013).

Decarbonisation thus hinges on regulations forcing low-carbon cement production, or otherwise creating a new market for low-carbon cement. Factors speaking in favour of this include the high cost-effectiveness

from a societal perspective of capital investments in cement decarbonisation, and the fact that the risk of carbon leakage is much less than for other sectors. Altogether, this makes the strict financial challenges of decarbonising Sweden's cement industry relatively low, but as noted above the business case obstacles are large due to large increases in production costs.

Refining

Eliminating CO₂ from Swedish oil refining adds cost to the product, albeit much less than for other sectors, and there is a clear risk for carbon leakage. However, removing CO₂ emissions from refining per se is not actually the key challenge. In a low-carbon future, there is simply no place for refining crude oil to fuel. Switching from oil to biomass feedstock, or moving to electro fuels with even higher cost, is thus needed for low-carbon liquid fuels (i.e. to the extent that such fuels are needed to complement electrification of transportation). Adding CCS to an industrial process with biomass as raw material would also enable Sweden to achieve negative emissions.

The challenges of switching feedstocks and regulatory developments with respect to biofuels and negative emissions dominate the business outlook and create significant uncertainty for the refining sector, adding to the financing challenge. That said, if the sector commits to biofuels, significant investment would still be needed. In summary, the financial challenges are substantial, with high costs and large uncertainties on both territorial process emissions and future markets for biofuels.

Petrochemicals

In many ways, the conversion of plastics production is the most complicated case to analyse. There are several conceivable competing strategies, including CCS with continued fossil feedstocks, bio-feedstocks, and mechanical and chemical recycling, with the latter being the pathway analysed in this report. Significant investments are needed to address both point-source emissions and end-of-life emissions, and there is a large need for financing. Production cost increases are also high, and there is a high risk of carbon leakage.

The size and integration of plant recycling infrastructure, and the connection to incineration of plastics today in heat and power sectors, make this an intricate investment decision, and very much a national, regional, and EU policy issue. If a chemical recycling system for plastics has similar economies of scale as current plastics production, only a limited number of recycling plants are needed in the EU, as these are large-scale industrial systems. In summary, the challenge for the petrochemical sector is capital-intensive, but regulations on material flows are critical and will determine whether there are viable new business cases.

What role should public/private risk-sharing play?

The analysis in this study shows that the costs for decarbonising heavy industry are manageable. However, it is also well known that in the absence of strong carbon pricing signals, the incentives for investing in new low-carbon production methods are low and the risks for individual companies are high. With the EU ETS system of free emissions allocations remaining in place over the coming decade, including for the four sectors covered in this report, there is a clear need to identify mechanisms for risk-sharing between private and public actors in order to accelerate the pace of change.

What is needed are both cross-sectoral efforts, such as ensuring access to electricity for the electrification of industrial production and quicker permitting processes, and sector-specific strategies to address the transition barriers faced by each industrial sector. Below we examine the types of risk-sharing measures that are already being used in Sweden and some of the key issues going forward in each sector.

Steel

Of the four sectors examined in this report, steel and petrochemicals appear to face the greatest obstacles related to capital needs for a transition to net-zero production. In Sweden, government grants have been important in advancing the decision to pilot a new hydrogen-based steel plant.

The Swedish Energy Agency (Energimyndigheten) is providing 528 million SEK in co-funding to HYBRIT, a project that is building a pilot plant testing the direct reduction of iron (DRI) ore with hydrogen, eliminating coking coal from the process and producing steel with very low total carbon emissions. The project is a collaboration between the Swedish steelmaker SSAB, the Swedish state-owned power company Vattenfall, and the Swedish mining company LKAB (the project also includes pilots of fossil-free pellet production and hydrogen storage). The government is covering just over a third of the total costs,¹⁰ and the funding comes from the SEA's Industriklivet (industry step) programme, which currently makes 600 million SEK available each year for investments in decarbonising industrial sectors, a figure that will increase to SEK 750 million from 2021.¹¹ The HYBRIT grant is by far the largest grant provided to date in this programme.¹²

The HYBRIT consortium recently announced an agreement to develop an industrial-scale demonstration plant, with construction slated to start in 2023 and be completed in 2026. The consortium is urging the government to increase its direct support of this project and to make funds available based on an Important Project of Common European Interest status.¹³ Projects deemed by the EU to have this status can receive amounts of public support that would normally be in conflict with the state aid rules of the EU's internal market.

10) See <http://www.energimyndigheten.se/nyhetsarkiv/2018/storsatsning-pa-varldsunik-anlaggning-for-fossilfritt-stal/>

11) See <https://www.regeringen.se/pressmeddelanden/2017/08/langsiktig-satsning-for-att-minska-industrins-utslapp-av-vaxthusgaser/>

12) The only other comparable grant was given to LKAB, part of the HYBRIT consortium, to test carbon-free mining (207 million SEK). Most other grants are around 10 million SEK or less. <http://www.energimyndigheten.se/forskning-och-innovation/projektdatabas/?AdvancedSearch=True&Organisation=&ProjectTitle=&ProjectManager=&ProjectNumber=&HandlingOfficer=&StartDate=&EndDate=&ProgramAreal=5&ExtractFromSummary=&ProgramId=27121>

13) See, e.g., <https://www.di.se/debatt/basindustrin-gor-en-fossilfri-omstart/>

Petrochemicals

Even though our analysis suggests that grant support for pilot and demonstration plants could be important in the petrochemicals sector, Borealis, Europe's second largest producer of polyeten and polypropen, has not received funding from Industrilivet for pilot projects. The company has espoused a circular economy strategy, but to date it has focused largely on mechanical recycling and its operations in Austria and Germany.¹⁴

There are already several chemical recycling plants in operation or development, including in Europe.¹⁵ Many are focused on plastics to fuel production, although some appear to involve a significant amount of plastics-to-plastics recycling.¹⁶ However, the role of chemical recycling in transitioning the plastics sector remains uncertain. There are several technologies at different levels of development, with varying environmental benefits and impacts and a number of obstacles to scalability.¹⁷ Some argue that chemical recycling is unlikely to ever play a large role, so the focus should be on reducing plastics usage, better sorting and more easily sorted product lines, and increased mechanical recycling.¹⁸

It is beyond the scope of this report to assess what the best balance is between mechanical and chemical recycling and between bio-based plastics and reduced usage. However, what is interesting from the perspective of financing is that major companies such as Coca-Cola, Pepsi, Nestlé and Unilever have made major commitments to significantly increase the amount of recycled content in their packaging by 2025–30, creating new incentives to invest in the recycling sector.¹⁹ The recent attention to the problem of plastic waste and expectations of increasing legislation appears to be creating at least a stronger business case for recycled plastics than in the recent past.

For petrochemicals, the abatement costs per tonne are very high, and thus the need for a much higher carbon price signal is clear. Moreover, creating a system where a large percentage of plastics can be processed for new production is a major challenge, given that in the EU only about 6% of plastic demand is met with recycled material, while most recovered plastic waste is incinerated, generating carbon emissions that are not covered by the EU ETS (Material Economics 2019, 102).

As noted above, regulatory developments are crucial to building a circular plastics economy. However, new opportunities are arising due to growing public attention to the problem of plastic waste, combined with the fact that plastics recycling adds very little to the cost of final products (less than 1%). Thus, although we find that costs, carbon leakage risks, and challenging technological pathways lead to very difficult conditions for incentivising low-carbon investments, societal and business drivers are pushing up demand for low-carbon production and creating a greater willingness to invest in this transition. For plastics it may be the case that with the right regulations in place, the need for public risk-sharing will be limited.

14) See <https://www.borealisgroup.com/polyolefins/circular-economy-solutions>

15) See <https://www.icis.com/explore/resources/news/2020/03/12/10481848/insight-new-chemical-recycling-technologies-proliferate>

16) See <https://recyclinginternational.com/business/basf-commits-to-chemical-recycling/28129/#:~:text=Chemical%20giant%20BASF%20is%20to,recycling%20of%20mixed%20plastic%20waste.&text=At%20BASF's%20-Ludwigshafen%20site%2C%20the,the%20dependency%20on%20fossil%20resources.>

17) See https://lup.lub.lu.se/search/ws/files/71014369/Plastics_and_sustainable_investments_download.pdf and <https://cen.acs.org/environment/recycling/Plastic-problem-chemical-recycling-solution/97/i39>

18) See <https://www.forbes.com/sites/emanuelabarioglio/2020/06/06/chemical-recycling-wont-solve-the-plastic-crisis-study-finds/#353d1f5c53d6>

19) See <https://cen.acs.org/environment/recycling/Plastic-problem-chemical-recycling-solution/97/i39>

Cement

Cementa, the Swedish branch of the international conglomerate Heidelberg Cement Group, and Vattenfall received funding from Industrikivet for a pre-study on the electrification of cement production, although this collaboration is no longer active.²⁰ Cementa currently has two ongoing projects related to electrification that have been granted a total of 11 million SEK.²¹

Cementa has called for public support both for the capital costs of CCS demonstration and for operating costs.²² It has also proposed public procurement agreements to ensure that there is a market for low-carbon cement, and it has asked the government to invest in a third transmission line to the island of Gotland, where its Slite plant is located.²³ The latter is to ensure sufficient electricity for the electrification of its production processes. In 2017, the Swedish transmission system operator (TSO) (Svenska kraftnät) decided not to build a third transmission cable to Gotland due to an unfavourable socio-economic cost-benefit analysis.

Given EU ETS carbon prices in the range of €20–30 per tonne CO₂ and continued free allowances to the cement sector over phase IV of the EU ETS (2021–2030), the exposure to carbon pricing appears far too low to incentivise investment in CCS. The Norwegian government has recently decided to support a major investment in industrial-scale CCS at Norcem's Brevik plant, which is also part of the Heidelberg Cement Group. The final decision is dependent on parliamentary approval of the government's proposed budget. Should the project go ahead, the Norwegian government will cover 75% of the capital investments and operating costs over a 10-year period at the Brevik production facility. The government will also pay for over 80% of the costs of transporting liquefied CO₂ and storing it under the North Sea.²⁴ The overall cost of the project is estimated to be 13.9–25.1 billion NOK (€1.3–2.3 billion), with the cost difference depending significantly on whether or not CCS at Fortum's heat recovery plant at Klemetsrud in Oslo is included in the project.²⁵

The Brevik case can only be partially indicative for Sweden, given that the Norwegian government's strategic investments in providing offshore CCS storage capacity to European industry creates an incentive for it to support the demonstration of industrial-scale CCS. Still, in comparison to steel, it appears that public support levels needed to incentivise investment in CCS for cement are much higher. This is largely explained by the much-higher OPEX increases for CCS on cement production compared with hydrogen-based steel production. For steel, the companies involved may perceive good opportunities for niche markets for "green steel", given limited increases in costs and good opportunities for public procurement of green steel in infrastructure projects.

The history of failed attempts to implement large-scale demonstrations of CCS in the EU suggests that direct public support for operating costs will be needed to incentivise serious investment in the cement sector, a perspective that is also taking hold at the EU level.²⁶ Yet it is also highly controversial to adopt a policy of paying polluting industries to cut their

20) See <https://www.cementa.se/sv/cemzero>

21) See <http://www.energimyndigheten.se/forskning-och-innovation/projekt-databas/?AdvancedSearch=True&Organisation=&ProjectTitle=&ProjectManager=&ProjectNumber=&HandlingOfficer=&StartDate=&EndDate=&ProgramArealId=5&ExtractFromSummary=&ProgramId=27121&StatusId=1>

22) See <https://www.cementa.se/sv/varldens-forsta-ccs-anlaggning-i-cementindustrin-planeras>

23) See <https://www.cementa.se/sv/varldens-forsta-ccs-anlaggning-i-cementindustrin-planeras> and <https://www.cementa.se/sv/fardplancement>

24) See page 13 of <https://www.regjeringen.no/contentassets/9f8d6e401b4e4f2e9d48645323aa26c0/kvalitetssikring-ks2-av-tiltak-for-demonstrasjon-av-fullskala-co2-handtering.pdf>

25) See <https://www.regjeringen.no/contentassets/9f8d6e401b4e4f2e9d48645323aa26c0/kvalitetssikring-ks2-av-tiltak-for-demonstrasjon-av-fullskala-co2-handtering.pdf>

26) See <https://www.euractiv.com/section/energy-environment/news/eu-clarifies-funding-scope-for-co2-capture-technology/>

emissions, particularly when sectoral actors lobby to minimise their exposure to carbon pricing.²⁷ Still, the cement sector represents a fraught political challenge for decision-makers. Neither public subsidies for a more rapid transition, nor delaying the transition until stronger pricing signals are in place, looks particularly attractive. Creating demand for green cement through public procurement commitments could be an effective strategy, given the large share of cement production consumed in public infrastructure projects, but this is still a subsidy in practice, and other support measures will likely be needed as well.

Refining

Preem, the Swedish petroleum company whose two refineries on the west coast make up 80% of the total Swedish refinery capacity, is currently piloting CCS with support both from the Swedish and Norwegian governments.²⁸ Preem and Vattenfall have previously conducted a feasibility study on the production of hydrogen from renewable energy sources, and together with Nordion Energi, Göteborg Energi, Renova, Göteborgs Hamn and St1, they are collaborating on a pre-study of the transport infrastructure needed for CO₂ destined to be captured under the North Sea. In all these projects have received just under 11 million SEK from the Industriklivet programme.²⁹

In 2020 Sweden's Land and Environment Court cleared the way for Preem to proceed with a major expansion of the Lysekil refinery.³⁰ This expansion would have made the refinery the single largest emitter in Sweden, and the government was set to decide whether or not to grant permission to the project. Preem argued that the expanded plant could be used for producing biofuels and said it planned to use CCS to capture half the emissions of its expanded production, covering a quarter of the expected total emissions.³¹ However, Preem subsequently withdrew its application for expansion in September of 2020, citing weak profitability for the project.³² Had the project gone ahead, it is important to note that Preem had stated that adoption of biofuel production and large-scale CCS would be dependent on economic viability and the right incentive structures.³³ As in the case of cement, given the high abatement cost per tonne of production and insufficient price signals in the EU ETS, it is difficult to see how large investments in CCS will occur without some form of public support.

What is the future of green industrial policy in Sweden?

It is clear that ensuring a low-carbon transition in heavy industry will require sizable and long-term support mechanisms that can quickly move industrial sectors through large-scale demonstrations and even commercial-scale efforts (Karlton et al. 2019). Yet much as the companies involved may want significant risk-sharing and investment support, it is unlikely that the Swedish government would take on a majority of the financing burden for the transition. If

27) See <https://www.reuters.com/article/us-health-coronavirus-eu-climatechange/investors-caution-cement-steel-firms-on-eu-climate-lobbying-idUSKCN21R2LU#>

28) See <https://www.di.se/pressreleaser/2019/2/27/preem-ab-preems-ccs-projekt-i-lysekil-far-ekonomiskt-stod-fran-energimyndigheten-och-norska-gassnova/>

29) See <http://www.energimyndigheten.se/forskning-och-innovation/projektdatabas/?AdvancedSearch=True&Organisation=&ProjectTitle=&ProjectManager=&ProjectNumber=&HandlingOfficer=&StartDate=&EndDate=&ProgramAreaid=5&ExtractFromSummary=&ProgramId=27121&StatusId=1>

30) See <https://www.dn.se/ekonomi/domstolen-lamnar-besked-om-preem/>

31) See <https://www.preem.se/om-preem/insikt-kunskap/2019/fragor-och-svar-om-preems-utbyggnad-i-lysekil/>

32) See <https://www.dn.se/ekonomi/preem-drar-tillbaka-ansokan-om-att-bygga-ut-preemraff/>

33) See <https://www.naturskyddsforeningen.se/nyheter/preems-grona-argument-ekar-tomma>

the state were to cover half of the upfront investment estimated in this report – for instance, as part of COVID-19 economic stimulus packages – the level of capital involved would be dwarfed by other types of investments pre- and post-pandemic, such as in transport infrastructure. Still, these upfront investment costs would not address increased operating costs, so for several companies, the incentives for investment would still not be sufficient.

As a rough initial estimate based on the figures from this study, we suggest that doubling or tripling direct public support from current levels throughout the coming decade would be enough to meaningfully accelerate larger-scale efforts and put Sweden on track to meet its climate targets. At the same time, we must emphasise the need to address challenges related to carbon pricing and policies for creating markets for low-carbon materials if a full-scale industrial transition is to be achieved.

Finally, a renewed period of green industrial policy may need to introduce new or scale up existing financing mechanisms backed by public funds. These mechanisms could include state investment funds, concessional green loans (for example, from existing or new public investment banks), loan guarantees, tax credits, and reductions in corporate taxes. Importantly, with rising expectations for public actors to share the risk of decarbonising heavy industry come questions about how the public is going to benefit financially from supporting private corporations. It is thus important to examine the best ways to provide public financial support over the coming years. Today we know very little about what impact different financing mechanisms could have in accelerating industrial transitions in Sweden.

Conclusions

This report has presented a sector-by-sector analysis of a set of industries that together emit about 17 Mt CO₂ per year – about one-third Sweden's GHG emissions – and examined the investments and financing needed to achieve net-zero emissions in each sector. We estimate that about 50 billion SEK (5 billion €) of additional capital above those investments needed to maintain current production levels using existing technologies, would need to be invested from 2020 to 2045 to decarbonise major steel, petrochemicals, cement and oil refining plants in Sweden that together account for 70% of the nation's industrial emissions. Another 15 billion SEK of investments would be needed to achieve sufficient negative emissions to offset the remaining 30% of CO₂ emissions from Swedish industry.

We find that the finance and capital challenges faced by each of the four sectors vary significantly, largely depending on how transformative the transition is. For cement production and oil refining, CAPEX needs for decarbonisation are relatively low, but the addition of CCS entails substantial OPEX increases that need to be covered in order to make these investments financially viable. In contrast, steel and petrochemicals require fundamentally new production processes

and larger upfront investments, but the OPEX effects vary significantly between the two. While for low-carbon steel, post-transition OPEX could turn out to be largely similar to those from today's process, OPEX for petrochemicals using recycled material would depend on systemic changes in material flows.

These distinctions highlight the need for targeted policy approaches to industrial decarbonisation. While capital and finance issues indeed are important for all sectors, for most sectors other issues are at least as important. In particular, issues related to available infrastructure in the form of high-capacity electricity supply (especially steel and oil refining) and CCS (oil refining, cement, and pulp and paper) are crucial. In addition, higher total costs driven by higher operational costs will have to be passed on to consumers, who may be more or less willing to pay for decarbonisation. Alternatively, new policy measures need to generate revenue to cover the additional expenses – for instance, for CCS. While the EU ETS could have a role to play here in the case of cement and oil refining, negative emissions (from BECCS) would not be covered, and hence would require an additional set of policy measures.

Given that 90% of emissions from carbon-intensive industrial production will continue to be covered by free permits until 2030 in Phase 4 of the EU ETS, there is a clear need to identify other mechanisms to accelerate the pace of change and avoid carbon lock-in. As a rough estimate based on the figures from this study, we suggest that doubling or tripling direct public support throughout the coming decade would be significant enough to accelerate large-scale efforts. At the same time, a number of challenges related to carbon pricing and policies for creating markets for low-carbon materials must be addressed to achieve an industrial transition in line with national and global climate ambitions.

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