2022

CLIMATE ROADMAP

for a competitive and fossil-free mining and mineral industry in Sweden

Fossil Free Sweden

SveMin

Roadmap for a competitive and fossil-free mining and mineral industry in Sweden

Interim Report III – follow-up and complementary analysis of energy needs and climate benefits

Report June 2022

About the report:

The mining and mineral industry's third interim report is a follow-up and complement to the climate roadmap and its subsequent interim reports published in 2018 and 2019, respectively.

The roadmap is a strategic project within the framework of Fossil-free Sweden. The project has been led and implemented by Svemin (project manager and project lead). The roadmap is based on two background reports: Material Economics (2021) – Klimatnyttan av svensk gruvnäring (English title: The climate benefits of the Swedish mining industry) and Sweco (2021) – Underlagsrapport klimatfärdplan gruv och mineralbranschen (English title: Background report for the climate roadmap mining and mineral industry).

The report is additionally based on material previously published by Svemin and the companies' own data. Other sources used in the preparation of the report are referenced throughout with sources footnoted.

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SWEDISH MINING INNOVATION

Med stöd från VINNOVA Sveriges innovationsmyndighet, Energimyndigheten, FORMAS, Strategiska innovationsprogram

The project is a part of and financed by Swedish Mining Innovation, a strategic innovation programme for the Swedish mining and metal extraction sector, which is a joint venture by Vinnova, Formas, and the Swedish Energy Agency.

Svemin – the Swedish Association of Mines, Mineral and Metal Producers – represents around 60 companies with more than 15,000 employees in mining, exploration and technology.

SveMin

Roadmaps for fossil free competitiveness

Within the framework of Fossil Free Sweden, 22 business sectors have developed roadmaps for fossil-free competitiveness, which have been submitted to the government. These roadmaps, which the sectors themselves own and manage, provide a narrative to how each sector will carry out their transition and what demands they place on politicians. Together, the roadmaps form a "Sweden puzzle" and by putting the pieces together it becomes clear how Sweden can, in practice, become fossil-free whilst creating jobs and export opportunities, and increasing welfare. This process is in itself unique in the world.

Sweden is now embarking on a green industrial revolution in which many companies from a wide range of sectors are accelerating their efforts to become fossil-free. At the same time, the conflict of interests that arise when the roadmaps are to be implemented are also becoming clearer.

There has been rapid technological developments and it is now time to upgrade the roadmaps. With the publication of this report, the mining and mineral sector is one of the first to develop an upgraded roadmap.

Since the publication of the first report in 2018, we have witnessed, for example, unexpectedly fast electrification – not least in the transport sector – which now affects not only the development of vehicles used in the mining sector itself, but also the demand for metals and minerals for batteries and sustainable energy systems. We are also seeing how circularity and recycling are intimately linked to mining in order to satisfy the increasing demand.

The mining and mineral sector is, as such, an enabler for other sectors to become fossil-free and more sustainable in a broader sense. In order to develop both primary mining and circular solutions, political barriers need to be removed. This also applies to permitting processes that need to be shorter, whilst mining technology itself needs to continue being constantly developed in order to reduce emissions and impact on water and biodiversity in mining areas. The fact that developments on this front are moving forward is a demonstration of both this roadmap and the strategy, Mining with Nature, that Svemin has developed to increase biodiversity in and surrounding mining areas.

In focusing on mining businesses opportunities and challenges, this roadmap shows that the mining and mineral sector plays a key role in the transition to a fossil-free Sweden.

Svante Axelsson, *National Coordinator, Fossil Free Sweden*

> The mining and mineral sector plays a key role in the transition to a fossil-free Sweden.

Svante Axelsson

About Fossil Free Sweden

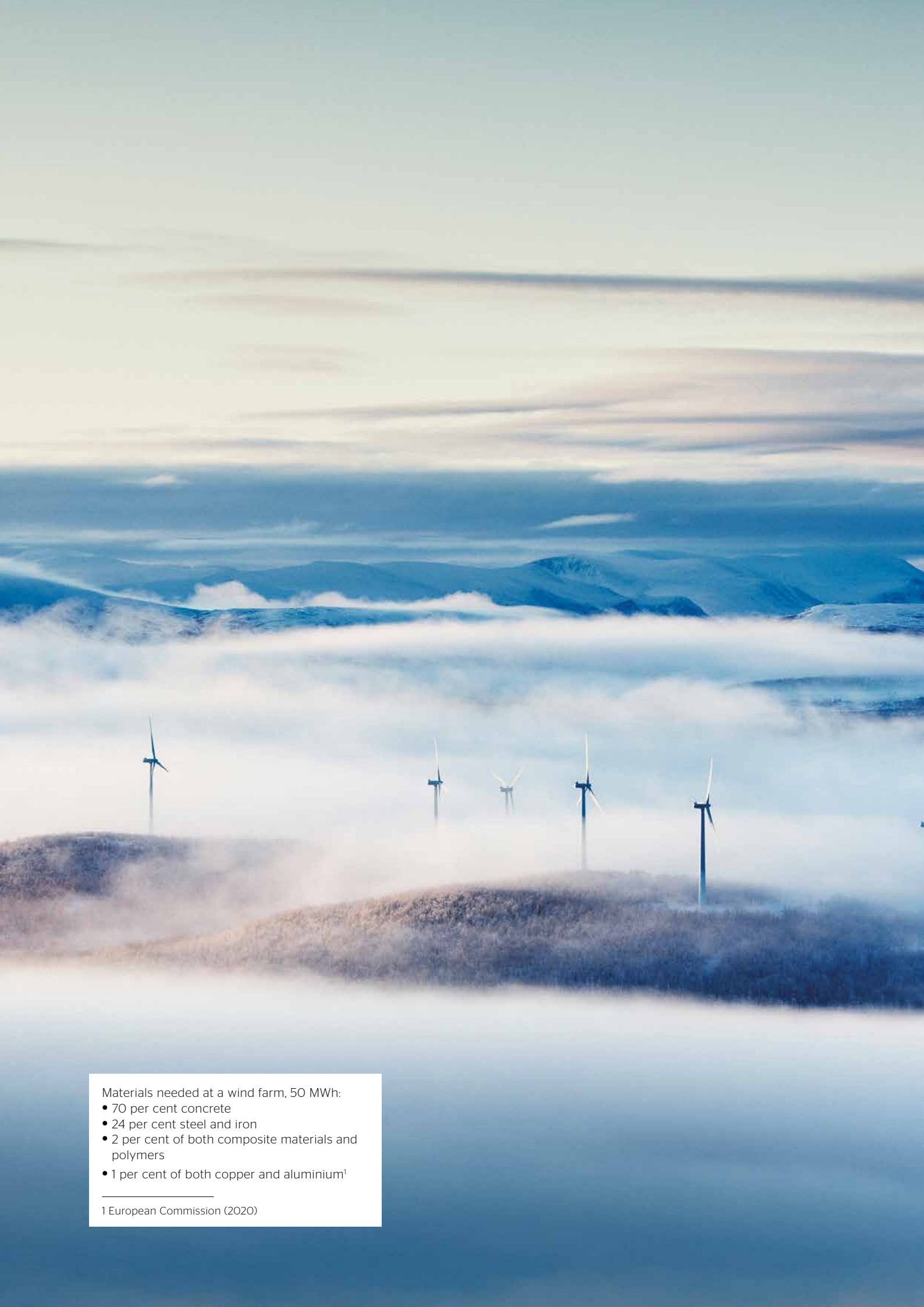
In 2016, the government appointed a national coordinator for a Fossil-free Sweden with the aim of accelerating the transition needed for society to become fossil-free. Over 500 actors consisting of companies, municipalities, regions, and organisations have supported the initiative's declaration that Sweden should be one of the world's first fossil-free welfare states.

Within the framework of Fossil Free Sweden, 22 business sectors have developed roadmaps for fossil-free competitiveness. The roadmaps were presented between 2018 and 2020 and contain each sector's own description of how it will become climate-neutral or fossil-free by 2045 at the latest, as well as what decisions on the political level that are required to achieve this. Fossil-free Sweden is currently developing strategies to address a number of the shared challenges identified in the roadmaps.

Strategies to date:

- Strategy for a sustainable battery value chain
- Hydrogen strategy
- Biostrategy
- Financing strategy

Fossil Free Sweden



Materials needed at a wind farm, 50 MWh:

- 70 per cent concrete
- 24 per cent steel and iron
- 2 per cent of both composite materials and polymers
- 1 per cent of both copper and aluminium[1]

1 European Commission (2020)

Foreword

The green transition begins in the mine

Without metals and minerals, it is not possible to produce the specific technologies required for the green transition of society. Wind turbines, solar panels, electric cars, and batteries all require metals to a greater degree than in the technologies currently in use. In addition, the green transition will be the single most important driver of the increasing demand for many metals until 2050.

A great deal has happened in the mining and mineral sector since the publication of the first climate roadmap in 2018. Our members have taken further steps to reduce their climate emissions and prepared roadmaps for strategic sustainability work. This forms the backdrop to this update of the sector's own climate roadmap. We want to show our development, progress, and plans for the future.

The Swedish mining and mineral sector is one of the most important industries in Sweden. The sector is of immense importance to Sweden in the regional and local perspective as well as beyond Sweden's borders. The mining and mineral industry is of importance for jobs, welfare, and the extraction of the metals and minerals necessary for the green transition of society.

Recycling is becoming increasingly important as the demand for metals increases. Companies in the sector have long been actively working on recycling for environmental, resource, and economic reasons and great progress is being made in developing circularity on an industrial scale. Many metals and minerals are very well-suited for recycling as they can be used repeatedly. However, recycling will only cover a small part of the increasing demand expected until 2050. The majority of metals required will still need to come from primary sources. Sweden has excellent opportunities to extract more. This underlines the need for Swedish mining, with a unique opportunity to become the driving force that the EU and the world need in the coming decades of green transition.

The Swedish mining and mineral sector's greenhouse gas emissions are low already today by international comparisons. This is due to the near fossil-free electricity system as well as investments in new climate-efficient technology. At the same time, the pace of development within the mining sector has not slowed down, on the contrary, it is currently undergoing major changes. Both the mining and metal production of today and in the future are significantly different to how the industry has been historically conducted.

Sweden has the opportunity to take a greater global responsibility for the green transition by taking advantage of the many opportunities that the Swedish mining sector offers. With the right prerequisites in place from the political level, the sector can be developed and contribute to the global efforts in combatting climate change.

This climate roadmap not only concerns the mining and mineral sector, it also lays the foundation for the other 21 sectors within Fossil-free Sweden to succeed in their own green transitions. Without sustainably produced metals and minerals – there can be no sustainable green transition.

The green transition begins in the mine.

Stockholm, June 2022

Maria Sunér *CEO, Svemin*
Hanna Stenegren *Director Energy and Climate, Svemin*
Sandra Lindström *Substitute Director Energy and Climate, Svemin*

> With the right prerequisites from the political level in place, the sector can make the transition and contribute to the global efforts in combatting climate change.

Maria Sunér

Hanna Stenegren

Sandra Lindström

Content

Battery-powered autonomous machines increase productivity and reduce the impact on the climate. The Sustainable Intelligent Mining Systems (SIMS) projects and the follow-on project NEXGEN SIMS aim to develop sustainable intelligent systems and technologies for autonomous, fossil-free underground mines.

Summary

The mining and mineral industry were among the first to develop a climate roadmap within the framework of Fossil-free Sweden. The sector's updated climate roadmap describes developments within the sector and how the goal of fossil-free mining by 2035 and the goals of climate-neutral processes and fossil-free energy use by 2045 will be achieved. The report also outlines the obstacles, challenges, and needs in implementing the plans.

A sustainable green transition requires sustainable metals and minerals

Sweden has long been Europe's leading mining nation and accounts for a significant part of the EU's production of metals and minerals. This due to our mineral-rich bedrock, responsible environmental legislation, and world-class innovation. To meet the goal of net-zero emissions globally, six times more metals and minerals will be needed compared with today – and many times more for some specific metals critical to the clean energy supply.[2] The demand for critical metals and minerals risks becoming a bottleneck and will set the pace for the green transition.

The EU depends heavily on imports for the many metals and minerals needed for new, climate-smart technology such as wind turbines, solar panels, and electric cars – many of these are produced in countries with low environmental standards and poor working conditions. Import dependence also poses a risk from a security policy perspective, particularly concerning dependence on individual countries such as China and Russia.

The Swedish mining and mineral sector – an important part of the solution

Sweden has the potential to mine many metals and minerals critical to the clean energy supply and innovation required for the green transition.[3] Half of the metals and minerals on the EU's list of raw materials considered critical for our society and welfare have been found in the Swedish bedrock.[4] The markets for these metals are global, and the demand not met by Swedish production is instead imported from other suppliers on the global market.

The sector's work on circularity and recycling

Many metals and minerals are very well-suited to the circular economy as they are elements that can be recycled without any significant loss of quality. Recycling is becoming increasingly important as the demand for metals increases. Companies within the sector have long been active in working on improved recycling for environmental, resource, and economical reasons, and great progress is being made in developing circularity on an industrial scale. There is great potential in improving the collection and recycling of minerals, including metals critical to innovation from electronic waste, and in recovering metals currently lost within the various material streams. More research and the development of resource-efficient, carbon-neutral processes are needed to enable both an increase in the yield of recycled metals and the extraction of additional elements that end up in slag, dust, and mud. Once fully developed, recycling is expected to cover 15–26 per cent of the demand for metals and minerals by 2050 and constitute an important complement to mining.[5]

The sector's current emissions

Swedish mining has already come far in its green transition journey. However, there remains much to be done. The sector currently accounts for 7 per cent of national emissions, which corresponds to 3.7 million tonnes of carbon dioxide emissions. Processing accounts for the vast majority of the sector's emissions, followed by mining transportation. These are described in more detail under the 2035 and 2045 targets.

2 IEA (2021) The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions.
3 Hallberg & Reginiussen (2018), SGU, Mapping of innovation-critical metals and minerals.
4 Copenhagen Economics (2021) The economic value of the Swedish mining cluster.
5 Svemin (2021) Climate ambitions and metal needs – opportunities for Sweden and the Swedish mining industry.

Fossil-free mining by 2035

The sector's goal is for all mining to be fossil-free by 2035. Reaching zero emissions primarily requires switching to fossil-free transportation, as well as automation and digitalisation, and also replacing the fossil fuels used in heating and ventilation.

Transportation, both above and below ground, is the biggest challenge in reaching the target, as it represents almost 90 per cent of the carbon dioxide emissions that mining accounts for. Today, diesel is the primary fuel used. The sector is investing foremostly in the full-scale electrification of mining, however there is also a view that biofuels or a combination of electric power and bioenergy can be a solution. Electric vehicles need to be charged and, as such, connected to the power grid and given the complexity and variety of the mines, stationary charging stations represent a challenge.

Climate-neutral processing and fossil-free energy use by 2045

The sector's goal is for all processes to be climate-neutral and energy use to be fossil-free by 2045.

The various processing stages are by far the most emission- and energy-intensive. Since these, in many cases, require extremely high temperatures, it is difficult to find alternatives to fossil-based fuels. Process-emissions can also occur as a result of the chemical transformation that takes place in the processing itself, for example during limestone burning, metal separation, and pelletisation. Reducing the energy intensity per product unit is a vital part of the green transition and also results in reduced energy costs.

Technological developments such as electrification or hydrogen use will be required to reach the target, likewise developments in carbon capture and storage (CCS). Hydrogen produced from fossil-free electricity is planned to be used in, inter alia, the reduction process in iron production. In order to reduce emissions, especially in the lime and cement industry, technological developments are planned to be used to capture and store emissions from processing through CCS. Both hydrogen production and CCS are energy-intensive technologies and require substantial amounts of electricity.

The green transition requires enormous amounts of electricity

By 2045, demand for electricity will increase 15-fold – from today's approximately 5 TWh to 74 TWh in 2045. This corresponds to half of Sweden's current electricity use, which will make the sector one of Sweden's largest electricity consumers.[6] The majority of the increased electricity demand will be required for LKAB's production of hydrogen which is then used to produce fossil-free sponge iron. During the same period, the sector's need for biofuels will increase six-fold, from today's approximately 1 TWh to 6 TWh.

Despite the increased energy usage, the sector estimates that the climate footprint and energy intensity per unit of volume produced will decrease due to more efficient processing, increased production, and recycling. Since the sector's green transition is based on a significantly increased demand for electricity, the need for competitive energy costs and a stable supply of fossil-free electricity will be crucial for the sector's companies to be able to decarbonize and implement the commitments outlined in the roadmap, and for Sweden to ensure it maintains a competitive mining and mineral industry.

> The sectors goal is for all mining to be fossil-free by 2035.

6 Ekonomifakta (2022) Elanvändning. (English title: Economics Facts (2022) Electricity Use).

The Swedish mining sector has a low climate footprint

Production of ore and metals in Sweden is 60–90 per cent less GHG intensive than equivalent international production. This is largely due to the near fossil-free electricity system in Sweden combined with investments in electrification, digitalisation, and the development of new inputs, processes, and equipment, which the Swedish mining cluster has invested in to transform operations to become less carbon-intensive.[7]

The Swedish mining sector's climate benefit has the potential to increase substantially

The reduction in global emissions that Swedish production enables, by replacing international production with a higher carbon footprint, corresponds to a global climate benefit of 6.4 million tonnes of carbon dioxide per year, according to calculations from Material Economics. By means of comparison, this corresponds to 40 per cent of the total emissions from the Swedish industry. By increased production and exports of Swedish climate-smart products can contribute to reduce emissions globally.[8]

By 2045, the climate benefit has the potential to increase by a further 37–43 million tonnes of CO2 per year – if the plans that Swedish companies have put forward for new mines, more advanced and fossil-free processes, a new generation of mining machinery, and further refinement using carbon-free energy and inputs can be implemented. Companies within the sector have shown that it is possible to, inter alia, produce fossil-free steel as well as green zinc and copper with a low climate footprint – less than half the global average.

The sector's companies are also world-leading suppliers of mining equipment used not only in Sweden but also exported elsewhere. This equipment can speed up electrification and lead to greater efficiencies within the sector globally. If the companies' plans (for half of all mining machines sold to be electrified by 2030) are implemented, global emissions could be reduced by 10-14 million tonnes of CO2 globally by 2035, with even greater climate benefits thereafter.[9]

Necessary prerequisites for the sector's green transition

There are a number of prerequisites that require policy actions and these are crucial for the sector's successful green transition. The most important are predictable and efficient permit processes and access to reliable fossil-free electricity at competitive costs. The sector has also identified the need for innovation in a number of areas, where the sector, in collaboration with other actors needs to develop and implement new solutions in order to reduce emissions. The sector's green transition also requires major investments, in total estimated to amount to SEK 450–500 billion.[10]

Goal 2035: Fossil-free mining

To achieve the goal, there needs to be:
- Rapid increase in electrification, automation, and digitisation
- Phasing out of fossil fuels used for heating and ventilation
- Replacement of vehicles and work machinery with electric and battery-powered alternatives

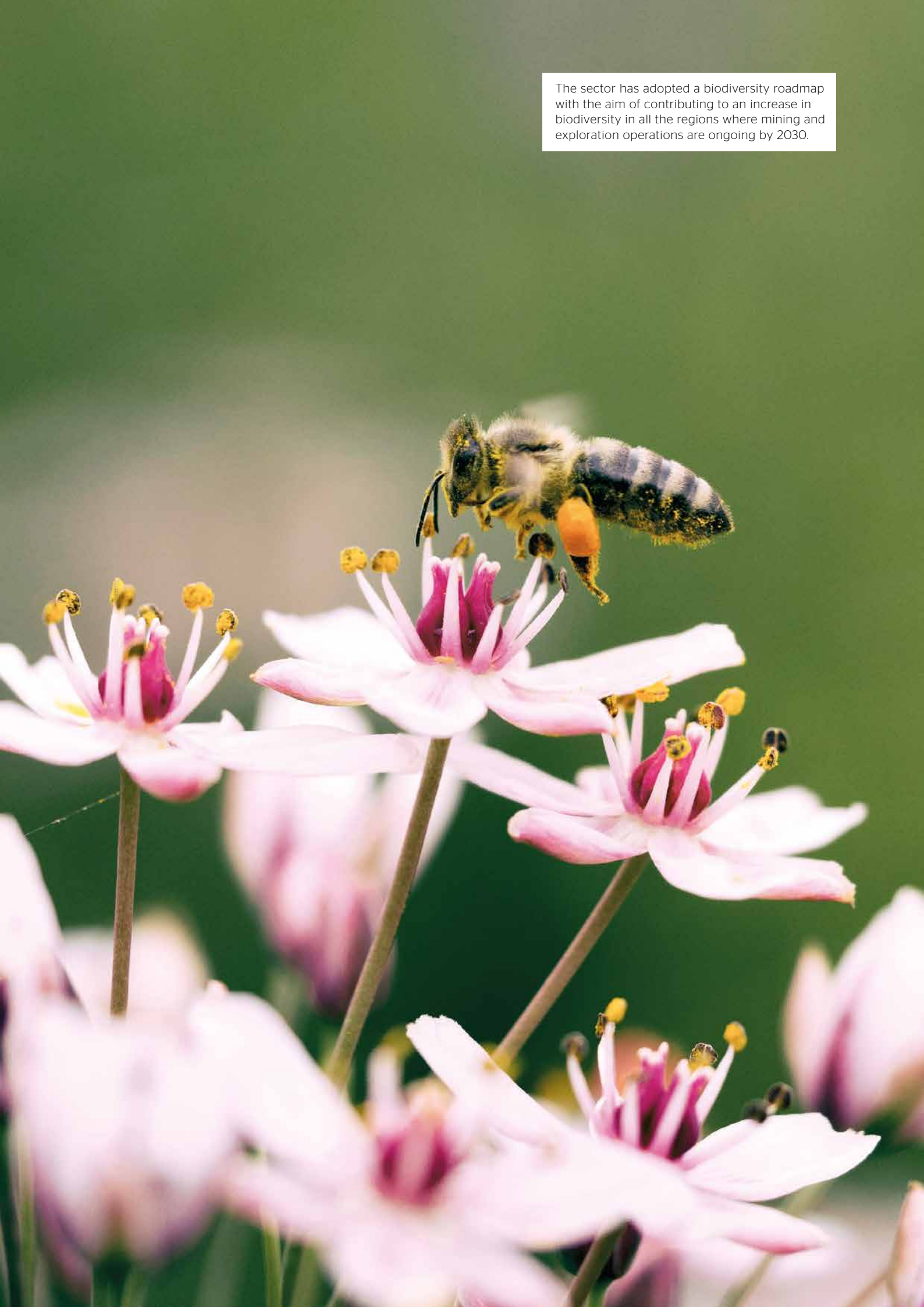
Challenges:
- High investment costs in electric vehicles
- Performance uncertainty and unstable electricity and fuel prices
- The complexity of mines makes charging infrastructure a challenge
- Lack of fossil-free explosives on the market

Goal 2045: Climate-neutral processes and fossil-free energy use

To achieve the goal, there needs to be:
- Developments in new refining processes
- New processes such as battery development, CCS and CCU, hydrogen production and storage
- Greater efficiency processes
- Major technological and system developments and gains as well as more inter-sector connections

Challenges:
- Stable access to electricity at competitive costs
- Development of fossil-free chemicals
- High investment costs for the transition

7 Material Economics (2021). Klimatnyttan av svensk gruvnäring. (English title: The climate benefits of the Swedish mining industry).
8 Material Economics (2021). Klimatnyttan av svensk gruvnäring. (English title: The climate benefits of the Swedish mining industry).
9 Material Economics (2021). Klimatnyttan av svensk gruvnäring. (English title: The climate benefits of the Swedish mining industry).
10 Sweco (2021) Underlagsrapport klimatfärdplan gruv och mineralbranschen. (Enlish title: Background report climate roadmap mining and mineral industry).



The sector has adopted a biodiversity roadmap with the aim of contributing to an increase in biodiversity in all the regions where mining and exploration operations are ongoing by 2030.

It is important that politicians and authorities set the level of ambition and the pace that industry needs to not only secure, but also take leadership in the green transition.

The sector's ten calls to action to the political level

The sector has identified ten calls to actions that are crucial in achieving the goals of fossil-free mining by 2035 as well as climate-neutral processes and fossil-free energy use by 2045.

1. Create efficient and more predictable permit processes

Politicians must take measures to make permit processes more efficient and predictable. This applies to electricity generation, as well as electricity grids and industrial activities. Efficient permit processes are a fundamental and crucial factor for the sector's long-term growth, where continued mining is critical to securing access to metals and minerals. In this respect, Sweden must also be more active in the various EU processes to ensure that the important regulations in the permit processes function well and are adapted to meet Swedish conditions.

2. Secure access to fossil-free electricity and biofuels at competitive costs

Without large investments in electricity grids and electricity generation throughout the country, both existing mineral and mining operations and the planned future projects are in jeopardy. The challenges in supplying stable and competitively priced electricity vary between the different regions and the country's electricity bidding zones. Whether companies are switching to electricity or biofuels, or both, the energy costs of the future will play a crucial role in companies' growth and increased profitability as well as in their ability to implement the green transition whilst maintaining their global competitiveness.

3. Enable hydrogen production and storage

Fossil-free hydrogen is important in enabling the sector's green transition and will play an increasingly important role in the energy system. A hydrogen strategy needs to be developed and regulations need to be drafted at both EU and national levels to promote hydrogen production and storage and the expansion of hydrogen infrastructure.

4. Develop a national strategy for capturing and storing carbon dioxide

Sweden should develop a national CCS strategy. In addition, targeted long-term public investments are needed to support the processing industry's competitiveness on its journey towards greater technological developments in low-carbon technologies.

5. Ensure a stable, long-term perspective in national and international climate policy for a competitive green transition

Climate policy should focus on creating the necessary conditions for the green transition instead of directing or forcing emission reductions. Swedish politicians should focus on influencing the EU's climate policy and the international climate agenda so that real emission reductions can be achieved whilst maintaining competitiveness. Ongoing amendments and revisions to regulatory frameworks at the EU level, such as the taxonomy (the EU Sustainable Investment Framework) and the Fit for 55 package (the EU's legislative package to reach the EU's new climate target of reducing emissions by 55% by 2030), must result in strengthening the domestic mining and mineral sector, rather than making conditions more burdensome and weakening companies' competitiveness. In several of our neighbouring countries, including Germany, the UK, France, Norway and Finland, industries receive compensation for the impact of the EU emissions trading system (EU ETS) on the price of electricity, something that Sweden should also implement to create the same prerequisites and conditions for Swedish businesses.

6. Support "front-runners"

Swedish mining and mineral companies compete on an international market where, at present, it is expensive competing with companies that have not yet started or come as far in their green transition. That said, the products of the future are expected to be sustainable as a key requirement, which provides incentives to initiate the transition already now. Some companies can naturally flex bigger muscles than others in this respect and, as such, have more capital to invest in climate-related measures. It is important that these companies receive sup-

Access to reliable fossil-free electricity at competitive costs will be one of the biggest challenges in tackling the sector's transition successfully. By 2045, the sector will require an estimated 74 TWh of electricity, which corresponds to around half of Sweden's current electricity production.

port, such as favourable conditions in the form of policy instruments and financial incentives, so that smaller companies can follow suit once the methods and techniques introduced are proven to work and produce results.

7. Create sustainable transportation systems for the future

The transition to electricity will require cooperation between companies in the energy, mining, and minerals sectors, battery manufacturers, software providers, and the automobile sector. Investments in rail, road, regional aviation, and shipping are all important in strengthening the sector's competitiveness and increasing its socio-economic impact. The government's electrification strategy and the measures presented therein should be implemented to facilitate the green transition of the transport sector.

8. Prioritise long-term research funding for sustainable raw materials

The green transition has increased the need for research and development to find new solutions that can contribute to achieving the goal of fossil-free production processes. Both expanding the opportunities for new testing facilities and scaling up successful projects are important for the sector. There are some processes where a transition today is not technically possible. Finding the necessary solutions requires that companies, academia, and the state work together. The financial support programme The Industrial Leap (*Industriklivet*) is a good example of the various initiatives aimed at enabling the sector's green transition.

9. Invest in recycling and metallurgy

There is great potential in improving the collection and recycling of minerals, including innovation-critical metals from electronic waste, and in recovering metals currently lost in material streams. Research in this area aims to develop resource-efficient, carbon-neutral processes that enable an increase in the amount of metals recycled and extract additional elements that end up in slag, dust, and mud.

10. Secure the right skills and knowledge to enable the green transition

The transition towards a carbon-free mining sector entails a number of operational changes, of which automation and electrification are perhaps the most evident. This requires a completely different range of skills amongst employees than before. The mining sector requires wide-ranging skills initiatives to manage the transition – everything from increased opportunities for postgraduate research to more relevant courses at the upper secondary education level. Without access to the right skills, large parts of the green transition risk being delayed or disappearing altogether.

The sector's needs and commitments

The green transition and the shift that the sector is facing requires major investments and a number of important innovations along the entire value chain. The sector's companies have initiated actions and projects either on their own or via cooperation with technology suppliers and other companies in the value chain. These will take time to implement and are capital intensive as many of the steps involve several, currently unproven technological advances. The entire transition is estimated to amount to SEK 450–500 billion.[11]

The sector is in agreement that the larger companies will need to take the first steps which will then pave the way for the smaller entities. Many of the larger projects are decades into the future, which means that consideration needs to be given to the expected prevailing conditions leading up towards 2045. These include not only different conditions in Sweden's energy system but also different conditions in the mines themselves. The following areas are crucial to the success of the transition:

Autonomous, smart machines

The development of autonomous machines has already come far, however continued development is needed to bring autonomous machines onto the market on a broad front. One area of development is to develop smart, connected control systems that enable the machines to communicate both with each other and with the overall process systems to optimise and increase the efficiency of mining.

Fossil-free explosives

The market currently lacks fossil-free explosives. There is a clear need for innovation to produce explosives that are both safe and as effective as today's explosives.

Chemicals and reducing agents

Chemicals and reducing agents used in enrichment and refining processes cause emissions of greenhouse gases. For some metals, the majority of the emissions in the production come from this enrichment and refining, e.g., rare earth elemets. In this respect, research and development is required to develop fossil-free chemicals that can replace those used in the current processes. Innovation is additionally required to replace fossil-based reducing agents used in metal production. The iron and steel industry currently has a clear plan to replace coke with fossil-free hydrogen as a reducing agent in the processing, but further technological developments are required to ensure that all metals processed in Sweden are completely fossil-free.

Fossil-free heating

Technology for fossil-free heating which is capable of producing high temperatures is a further key area of development. Several Swedish companies are currently investigating the opportunities for both the direct use of electricity and of fossil-free hydrogen and biofuels.

Create commercial solutions to utilise and store carbon dioxide

In order to prevent industrial emissions being released into the atmosphere, commercial, large-scale solutions need to be developed to utilise carbon dioxide in industrial processes (CCU) and geologically store carbon dioxide (CCS).

Safe and efficient battery systems and related infrastructure

Fire safety in a mine is of the utmost importance, and the use of electrically powered machines in underground mines, which is one of the prerequisites for fossil-free mining operations, entails new fire safety requirements. Swedish machine suppliers have already come far in this respect, but continued research as well as technological developments and subsequent demonstrations are required to provide evidence of the adequate safety and efficiency of using batteries underground.

11 The basis is the companies' own plans and assessments, which have been aggregated by Sweco.

The sector's climate and sustainability goals

The mining sector has jointly adopted a range of high-level goals for its climate and sustainability work. These point to the long-term direction of the work that the sector's companies are committed to carrying out and require both a strong commitment and large investments from the companies to become a reality.

Climate

Goal: Mining to be a completely fossil-free operation by 2035 and achieve the goal of climate-neutral processes and fossil-free energy use by 2045.
What is needed: Efficient and predictable environmental permit processes to ensure the new and necessary climate-efficient investments can become a reality, as well as access to fossil-free electricity and biofuels at competitive costs.
Read more: *Interim Report I – Roadmap for a competitive and fossil-free mining and mineral sector; Interim Report II – Follow-up and complementary needs analysis*

Biodiversity

Goal: To contribute to increased biodiversity in all the regions where mining and exploration are ongoing at the latest by 2030.
What is needed: Removal of barriers by the political level and closer cooperation between businesses, authorities, and civil society.
Read more: *Mining with Nature – The Swedish mining and minerals industry's roadmap for biodiversity net gain*

Reindeer husbandry

Goal: The mining industry and reindeer husbandry to co-exist in the long run with a fair, positive, and respectful dialogue.
What is needed: Clear legislation and regulations as well as the state taking responsibility for balancing future land use in order to allow for both reindeer husbandry and mining. That all parties work to achieve and maintain a good dialogue in order to find suitable solutions that minimise the impact on reindeer husbandry.
Read more: *Position Document – Indigenous People and Mineral Extraction*

Working environment – health and safety

Goal: That our companies' workplaces should be accident-free and zero work-related ill-health.
What is needed: Good cooperation and that legislation and regulations in the work environment area are reasonable, practical, and, in addition, achievable.
Read more: *Svemin's work environment committee, GRAMKO*

Research and innovation

Goal: The Swedish mining cluster is to be a global leader in terms of technological development and research in mining and mineral-related issues.
What is needed: Large-scale, nationally targeted investments in both basic and applied research for a sustainable mining and mineral sector.
Read more: *Strategic research and innovation agenda for the Swedish mining sector and metal-extracting sector*

Recycling

Goal: To recycle as many residual products in production as possible and to work towards further synergies between primary and secondary raw materials.
What is needed: To increase recycling further, more knowledge, technological developments and amended policy instruments, market instruments, and incentives are all required as well as the targeted coordination of different bodies and infrastructure that enable the implementation of these measures.
Read more: *LKAB's circular industrial park.*

> The mining and mineral sector needs to claim new land to be able to develop. Mines are not able to choose which land they operate on and instead can only be based where the metals and minerals are found.

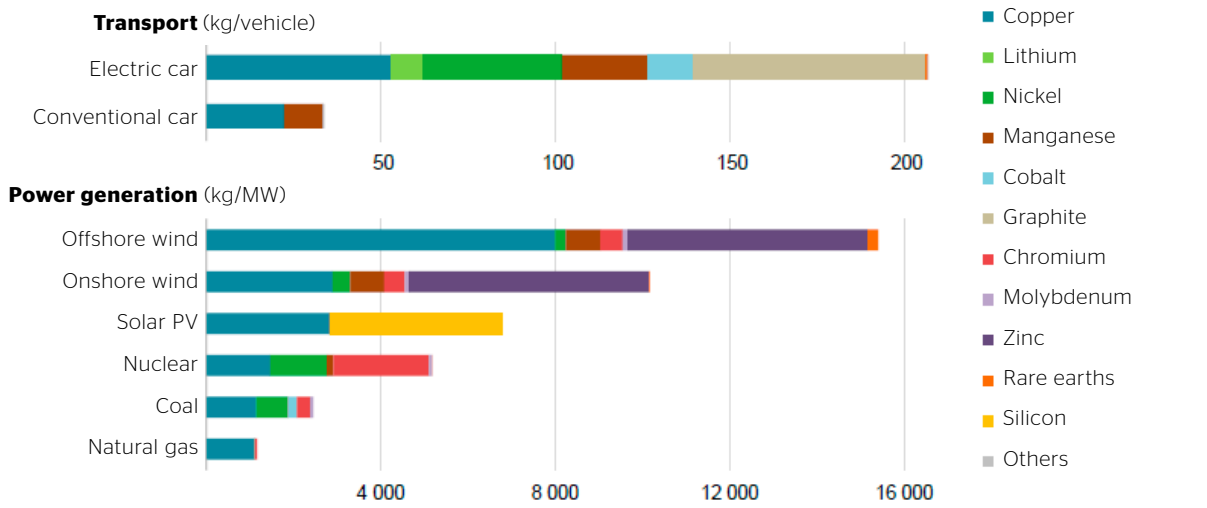
The societal challenge: A sustainable green transition requires sustainable metals and minerals

The green transition increases the demand for metals and minerals

Many trends and changes in society affect the various needs for metals. The green transition will be the single most important factor affecting such needs until 2050, especially for metals critical to the energy supply. According to the International Energy Council (IEA), in order to meet the goal of net-zero climate emissions, six times more metals and minerals are needed compared with today – and many times more for some specific metals critical to clean energy production and supply.[12] [13]

Three changes linked to the green transition will have a particularly large impact on the demand for metal – the shift to electric battery-powered vehicles, the expansion of renewable electricity (especially solar cells and wind power), and the expansion of the electricity grid, which is a result of the fact that many parts of the economy need to be electrified as fossil fuels are phased out.[14]

Metals and minerals used in transition-related technologies



The shift from coal and gas to renewable energy sources increases the requirement for metals by 10–50 times to produce the same amount of electricity. An offshore wind plant requires thirteen times more metals and minerals than a similarly sized gas-fired power plant. The requirement for metals in an electric car is six times greater compared to a conventional car.[15]

> Many metals and minerals are currently produced in countries with low environmental regulations, a high climate footprint, and poor working conditions.

More recycling is needed but does not cover the increasing demand for metals and minerals

To meet the growing demand for metals, recycling, reuse, and other circular methods are an important part of the future. It is, therefore, only natural for the sector to contribute to the realisation of this on a larger scale. However, recycling is far from sufficient in itself to meet the increasing demand.

Maximised recycling will only meet approximately 15–26 per cent of the demand for primary metals by 2050.[16] This is because there will be insufficient volumes of minerals in the cycle and many products will be used for a long time and will, therefore, be unavailable for recycling for some time. For example, it will take until 2100 before recycling can account for half of the amount of rare earth elements that we expect Europe, and

12 The so-called energy-critical metals include lithium, cobalt, nickel, indium, and rare earth elements, among others. Lithium, cobalt, and nickel are some of the metals needed to turn batteries into electric vehicles and energy storage. Indium is used in some solar cells and rare earth elements are used in, for example, wind turbines and electric motors. For these metals, more than half of the future demand will come from clean energy technologies.
13 IEA (2021) The Role of Critical Minerals in Clean Energy Transitions.
14 Svemin (2021) Climate ambitions and metal needs – opportunities for Sweden and the Swedish mining industry.
15 IEA (2021) The Role of Critical Minerals in Clean Energy Transitions. Svemin (2021) Climate ambitions and metal needs – opportunities for Sweden and the Swedish mining industry.
16 World Bank (2020) Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition.

the world will then need.[17] Clearly the vast majority of the metals needed will, therefore, have to be mined for a long time to come. It is not an issue of either recycling or primary mining – both are needed to satisfy the increasing demand in the future.

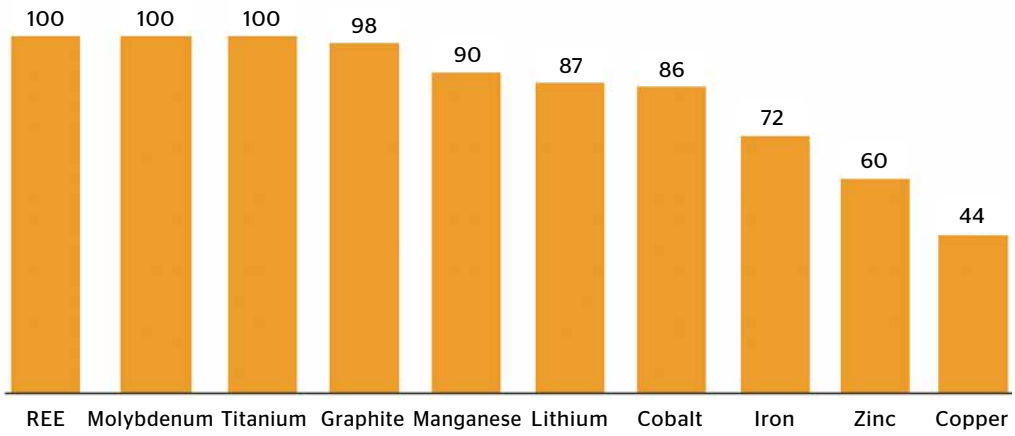
The EU's heavy dependence on the import of metals and minerals constitutes a vulnerability

In Europe, we consume around a quarter, but produce only three per cent, of the world's raw materials.[18] Currently, the EU produces only 1 per cent of the raw materials needed for the production of wind energy, solar energy, lithium batteries, digital technologies, and medical equipment, and only 2% of the raw materials used in robotics.[19] As such, Europe has a high dependence on the import of many metals and minerals to cover both the EU's current needs and to be able to transform society in the long term. For example, 100 per cent of all rare earth elements as well as almost all graphite, lithium, and cobalt are imported.[20]

Many metals and minerals are currently produced in countries with low environmental regulations, a high climate footprint, and poor working conditions. Moreover, import dependency, especially where a substantial proportion of the supply comes from one or a few countries, creates great uncertainty in terms of security of supply, transparency in the value chain, and geopolitical risks.[21]

Import dependency of selected metals and minerals
Europe imports a majority of the metals it requires. For some metals the EU is completely dependent on imports.

Level of dependency on imports per metal
Per cent



Note: Import dependence on extraction (non-processing)
Source: Study on the EU's list of Critical Raw Materials (2020)

> In order to meet the goal of net-zero climate emissions, six times more metals and minerals are needed than today – and many times more for some specific metals critical to clean energy production and supply.

Boliden is a driving force behind developing the electrification of mining operations across the globe. We are carrying out a transition to make our mining operations fossil-free – and it's urgent. All investments must be profitable, we are price-takers in a world market, so costs are our opportunity to survive. The cost of electricity is the most important and crucial part of our cost structure – if it is unavailable, the transition will stop, and investments will dry up in Sweden.

Mats Gustafsson, Vice President Energy, Boliden

17 SGU (2021) Critical raw materials.
18 SGU (2021) Critical raw materials.
19 Kejerhag, Jenny (2021).
20 European Commission (retrieved 2022) Critical raw materials.
21 Copenhagen Economics (2021) The economic value of the Swedish mining cluster.

EU är oerhört importberoende av flera energikritiska metaller och mineral – för flera upp till 100 procent.

The availability of critical metals and minerals risks becoming a bottleneck in meeting the climate targets

Europe's dependence on importing metals and minerals, and the vulnerability this entails, is the reason the EU has listed 30 metals and minerals that are considered critical for our society based on their economic importance and availability. An important aspect of the EU's raw materials strategy is to increase the EU's self-sufficiency of critical metals and minerals to ensure their access and availability.[22]

Today, there is a clear and somewhat threatening imbalance between the world's tough climate ambitions and the availability of critical minerals. If the demand cannot be met, the technological developments needed to tackle climate change risk both slowing down and becoming more expensive – thereby hampering the ability to reach the climate goals set.[23]

In the short term, the supply of certain metals and minerals necessary for the green transition is expected to become scarce as demand increases. In the medium term, this will apply to most metals and minerals, as the expected demand exceeds the expected supply from existing mines and projects underway.[24]

This means that significant investments will be required both within the EU and globally to meet this increasing demand. Due to the often-long lead times for new projects, there is a clear risk that the green transition will both slow down and become more expensive due to shortages of metals and minerals.[25]

Expanding domestic production is a means of improving the security of supply and ensuring the metals and minerals are produced in sound working conditions, in compliance with tough environmental regulations, and with a low climate impact from an international perspective.

At present, the production of many minerals critical to the energy production and supply needed in the transition to a climate-neutral society is more geographically concentrated than oil and gas.
The chart shows the share of production of certain minerals and fossil fuels in the top three countries produced.

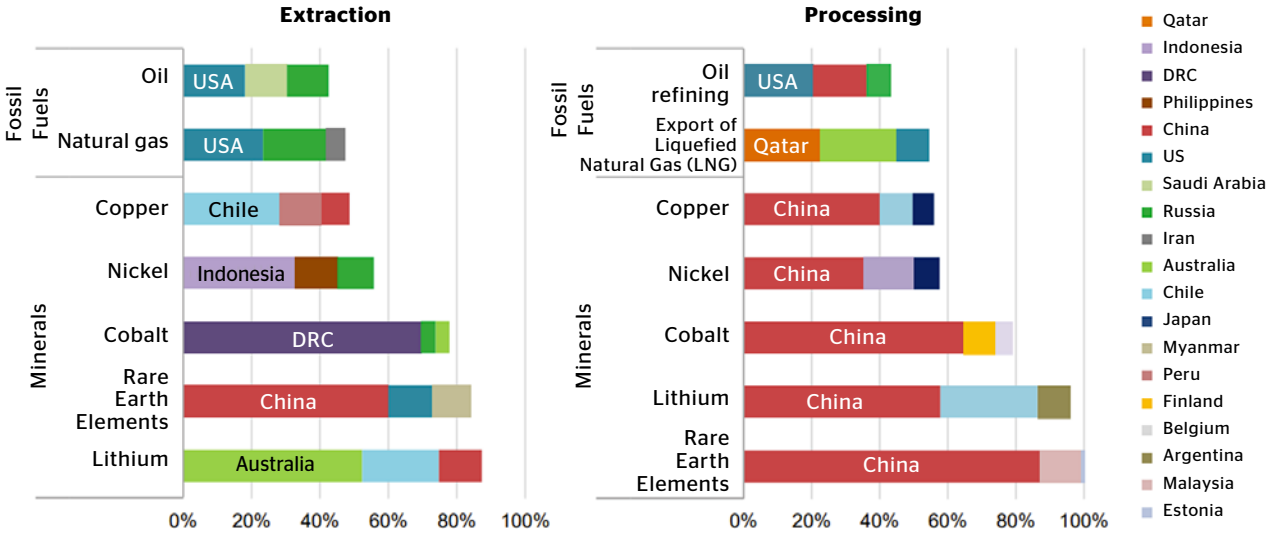


Image source: IEA (2021) The Role of Critical Minerals in Clean Energy Transitions.

22 Inter alia, Sweden has known deposits of antimony, fluorspar, phosphate minerals, graphite, cobalt, PGE (platinum group elements), REE (rare earth elements), and tungsten. Source: SGU (2021) Critical raw materials.
23 IEA (2021) The Role of Critical Minerals in Clean Energy Transitions.
24 IEA (2021) The Role of Critical Minerals in Clean Energy Transitions.
25 IEA (2021) The Role of Critical Minerals in Clean Energy Transitions.

Swedish companies are world-leading producers of mining equipment. Epiroc and Sandvik SMRT have approximately 60 per cent of the market share for underground mines globally. They offer battery-powered models and have ambitious initiatives to replace today's diesel-powered machines with electric alternatives

The Swedish mining and mineral industry plays a vital role in the green transition in Europe and the world

12 mines
Sweden currently has twelve active mines – half of them are more than 50 years old. At the beginning of the 20th century, Sweden had around 250 active mines, yet despite the decrease in the number of mines, total production has more than doubled.

Sweden is Europe's leading mining nation

Sweden has long been Europe's leading nation for mining. This is thanks to our mineral-rich bedrock, responsible environmental legislation, and world-class innovation. Almost all (over 90 per cent) iron ore produced in the EU originates in Sweden, and we are also one of the main producers of other base metals. The markets for these metals are global, and production that is not met by Swedish production is instead imported from other suppliers on the global market.[26]

Of the total EU production, Sweden accounts for:

93 per cent of all iron ore.
32.8 per cent of all lead.
34.4 per cent of all zinc.
18.8 per cent of all gold.
18.3 per cent of all silver.
10.7 per cent of all copper.

Source: Svemin[27]

The Swedish mining and mineral sector can:

- Reduce the climate footprint of the green transition.
- Limit the local environmental impact of metal and mineral extraction.
- Limit unethical extraction in, for example, African countries.
- Reduce geopolitical dependence on China and undemocratic states for Sweden's and Europe's green transition.

Swedish mining in numbers

- Accounts for 3 per cent of GDP and contributes to more than SEK 25 billion per year in tax revenues and dividends to the state.[28]
- Accounts for 13–20 per cent of the total annual industrial investment in Sweden, 5 per cent of foreign direct investment in Sweden, and 75 per cent of planned investments in the regions Norrbotten and Västerbotten in the coming years.[29]
- The mining cluster provides around 100,000–125,000 direct and indirect jobs.[30]
- Makes major investments in tackling climate change – of the more than SEK 75 billion invested between 2010 and 2019, the majority went into fossil-free production.[31]
- Accounts for approximately 8 per cent of total Swedish exports, and if the export of mining equipment is included, the mining industry accounts for close to ten per cent of Sweden's total exports of goods and services.[32]

Source: Svemin (2021) Climate ambitions and metal needs – opportunities for Sweden and the Swedish mining industry. Copenhagen Economics (2021). The economic value of the Swedish mining cluster – today and in the future

Talga aims to become not only the world's greenest, but Europe's largest, battery anode company. It is important that politicians and authorities maintain both the level of ambition and the momentum that the sector needs to not only ensure but also take leadership in the green transition. The sector's ten calls for political action are critical to meeting our shared challenges.

Martin Phillips, Chief Executive Officer Europe / Group COO, Talga Group

26 Svemin (2020): Swedish mining industry in numbers.
27 Svemin (2020): Swedish mining industry in numbers.
28 Copenhagen Economics (2021): The economic value of the Swedish mining cluster – Today and in the future.
29 Copenhagen Economics (2021): The economic value of the Swedish mining cluster – Today and in the future.
30 Copenhagen Economics (2021): The economic value of the Swedish mining cluster – Today and in the future.
31 Svemin (2020): Why the Swedish mining industry is important for Sweden.
32 Svemin (2020): Swedish mining industry in numbers.

Enormous potential in Sweden for critical metals and minerals

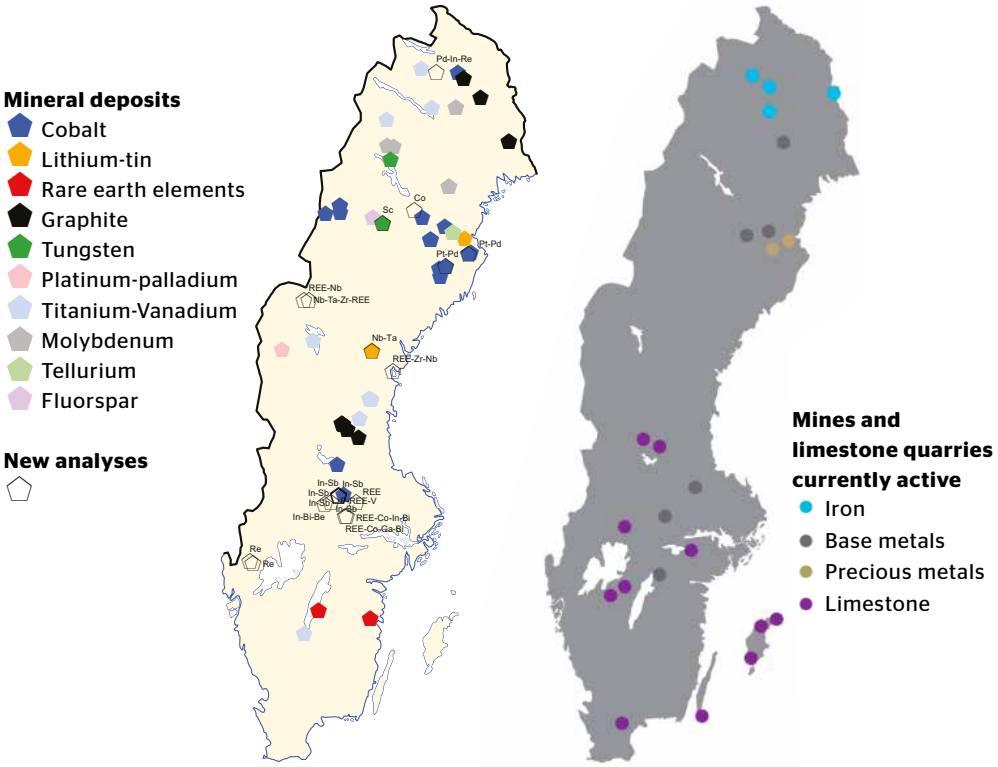
In Sweden, there is the potential to mine over half of the elements on the EU's list of critical raw materials.[33] We have deposits of graphite and rare earth elements that can cover a significant part of Europe's needs. Cobalt has also been found in several places in Sweden, and if permission were granted, we could produce cobalt that is sustainable from both a climate and social perspective. There are also rich deposits of metals of central use in society such as iron and copper. The Swedish bedrock is underexplored, which means that there may be even more deposits than we are currently aware of.[34]

The deposits investigated to date have provided positive results. Regardless of this, not a single new mine, despite having been subject to both the Swedish Environmental Code and the Swedish Minerals Act, has been opened beyond the already established mining areas in the past twelve years. The lengthy permit processes are a major barrier to the development of the sector as well as to the green transition.

Likewise, it is possible to expand and develop the extraction and reuse of produced material in existing facilities. Sweden has every opportunity to establish its position as Europe's leading supplier of sustainably produced metals and minerals.

Estimated ore deposits with critical raw materials in Sweden

There is geological potential to extract several critical metals and minerals in Sweden



The image on the left shows estimated ore deposits in Sweden where there is the geological potential to extract more critical metals and minerals. The image on the right shows the mines and limestone quarries currently active. Sweden's mines and limestone quarries make up 0.04 percent of Sweden's surface. This is less than Sweden's golf courses, which make up 0.07 per cent[35] and reindeer herding areas, which make up almost half of Sweden's surface area.[36]

Source: Hallberg & Reginiussen (2018), SGU, Mapping of innovation-critical metals and minerals

Critical raw materials

Graphite. Important mineral for manufacturing steel, batteries, and cars.

Cobalt. Used in batteries. Demand is increasing due to the growing market for electric vehicles. Extracted mainly in the Democratic Republic of the Congo.

Rare earth elements. Huge increase in demand in line with the ever-higher demand for green and smart technology. Important for modern green technology, for example in wind turbines and electric vehicles. At present, production is mainly concentrated to China. More deposits to secure supplies are needed, not least for the EU, whose industries depend on access to rare earth elements.

Source: SGU

33 The EU's list of critical raw materials is regularly revised. The latest list is from 2020.

34 SGU (2021) Critical raw materials.

35 Svemin (2020): The total area for Sweden's.

36 Sami Parliament (retrieved 2022): Ordförklaringar Rennäring (English title: Glossary raindeer breeding).

	Typ of deposit	Company	Description
Kallak	**Iron ore**	Jokkmokk Iron Mines	Deposit of magnetite ore about fourty kilometers outside of Jokkmokk. Possible mining of about 3 Mt of iron ore concentrate per year. Can become an important part of a value chain for producing fossil-free steel in northern Sweden.
Vittangi	**Graphite**	Talga Group	Deposit of graphite in Kiruna municipality intended to be mined to produce anodes for lithium-ion batteries. The world's highest-grade graphite deposits, which are expected to meet a large part of Europe's needs by 2025.
Norra Kärr	**Rare earth elements**	Leading Edge Materials	In Norra Kärr, outside Jönköping, there is one of the largest known deposits in the world of heavy, rare earth elements. It represents an opportunity for production that can cover large parts of Europe's needs for a number of metals.
Laver	**Copper, gold, silver**	Boliden	Deposit of copper and other precious metals outside Älvsbyn in Norrbotten. A former mine which was in operation during the 1940s is located in the area, and where Boliden has been active in mining, even into the 2000s. Possible production of around 100 kt copper per year.

There is great potential for increasing the extraction of more metals and minerals in Sweden – if only permission were granted. Above are a number of examples of projects that are under development.

Talga's graphite becomes anode material for green batteries

What: Talga's graphite project in Vittangi is expected in its first stage to supply the market with 19,500 tonnes of finished anode material per year for 24 years. This, in turn, is enough to supply anodes for roughly 200,000 newly produced electric cars each year.

When: Ongoing, the first step of the environmental permit process in court is completed. The main hearing in the case will be held during Jan-Feb 2023.

Cost: Approximately SEK 4.8 billion (USD 484 million).

Changing market: As one half of the active materials in a lithium-ion battery, green anodes can dramatically reduce the CO_2 emissions of making electric vehicles, energy storage systems and consumer electronics. Talga's natural graphite anode material Talnode®-C has an extremely low climate footprint. A 2021 life cycle analysis conducted by Hitachi ABB Power Grids shows that Talnode-C® has a mere 1.48 kg of CO_2 equivalent per kg of finished anode material.

Magnetic metals from Norra Kärr

What: Leading Edge Materials' (GREENNA Mineral AB) project for mining and extraction of rare earth elements. Mining 1,150,000 tonnes per year of ore for 26 years can provide earth metal oxides sufficient for the production of strong permanentmagnets for 1–2 million electric cars per year. Over 26 years, only a third of the total estimated mineral resource of 110,000,000 tonnes will be mined.

When: An exploitation concession was granted for the project in 2013 but was then returned to the status of an application in 2016 following a ruling by the Supreme Administrative Court. The Mining Inspectorate of Sweden rejected the application in 2021, due to no Natura 2000 permit having been granted.

The company is now working on a Natura 2000 permit and subsequent exploitation concession applications based on a significantly revised plan for the project, whereby the planned operations are separated into two parts, a mine quarry on site in Norra Kärr and a separate wet chemical plant elsewhere.

Cost: Approximately USD 487 million, of which a third is for the operations on site in Norra Kärr.

Changing market: The changes remove the need for large tailings dams on site in Norra Kärr. Since the type of rocks in Norra Kärr are alkaline, it is also expected that the waste rock can be sold as aggregates. The rare earth element deposit in Norra Kärr has one of the lowest levels of uranium and thorium globally, which can otherwise cause challenges in waste management. Research has shown that the extraction of rare earth elements from Norra Kärr would mean a greatly reduced impact on the environment and climate compared to existing production in China, the United States, and Australia.

Increased recycling of metals and minerals

Recycling materials will play a crucial role as the future demand for metals increases and the environmental impact of production is reduced[37]. However, even if recycling were to reach 100 per cent, this would be insufficient in meeting the future needs. Mining and recycling will need to expand and develop in parallel to ensure the growing demand is satisfied.

Since the 1950s, the recycling of precious metals and scrap containing iron, steel, and base metals has increased sharply. For example, steel recycled from scrap has increased from 50 to 92 per cent in 2010. For metals that have been less common, recycling is still modest.[38] Companies in the mining sector are already working to recycle sizeable portions of mining waste and scrap metal, in parallel with expanding mining operations to meet the increasing demand for metal and minerals. Swedish mining is a world leader in the material recycling of electronics and currently recycles half of Europe's electronic waste. For example, Boliden is one of the world's largest recyclers of metal from electronic materials and one of Europe's largest recyclers of lead batteries.[39] [40]

The sector is investigating further ways to manage resources more efficiently and develop circularity on an industrial scale, both for environmental, climate, and economic reasons and to reduce dependence on importing, inter alia, critical raw materials. There are plans under development to extract more metals from mining waste in order to utilise resources more efficiently than is done today. However, there can be technical difficulties in recycling certain metals. Our metal production of so-called primary raw materials from bedrock is often supplemented with recycled raw material from waste. Combining primary and recycled raw materials in the refining process is good for both the environment and the economy.[41]

Increasing recycling also requires additional knowledge, technological developments, and amended policy instruments as well as the targeted coordination of different bodies, infrastructure, market instruments, and incentives.

> Sweden has the potential to mine many of the metals and minerals needed for the green transition.

LKAB's circular industrial park – from mining waste to valuable products

LKAB plans to extract metals and minerals from mining waste. The waste material from iron ore production will be used as a raw material to extract, inter alia, phosphorus and rare earth elements. The project has the potential to meet 30 per cent of the EU's need for rare earth elements, five times Sweden's need for phosphorus mineral fertilisers, and 100 per cent of Sweden's need for gypsum.

37 SGU (2022) Metal and mineral recovery.
38 SGU (2022) Metal and mineral recovery.
39 Boliden (2022) One of the largest recycler of electronic material.
40 Sweco (2021) Underlagsrapport klimatfärdplan gruv och mineralbranschen. (English title: Background report climate roadmap mining and mineral industry).
41 Svemin (2020) Heavy facts about the mining industry.

Companies in the sector are world-leading suppliers of mining equipment used not only in Sweden but also exported, which has the potential to be the driving force for the faster electrification and greater efficiency in the sector globally. If the companies' plans for half of all mining machines sold to be electrified by 2030 are implemented, global emissions could be reduced by 10-14 million tonnes of CO2 globally by 2035, with greater climate benefits thereafter.

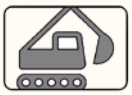
The sector's current emissions

Sweden's climate goals entail reducing greenhouse gas emissions to net zero by 2045. When the first roadmap was published in 2018, the mining and mineral sector accounted for 8 per cent of Sweden's total carbon dioxide emissions – which corresponds to approximately 4 million tonnes of carbon dioxide (tCO_2e). By 2020, the sector's emissions had decreased to approximately 7 per cent of national emissions, equivalent to 3.7 million tCO_2e.

The mining, metals and minerals sector can be broken down into three main parts.[42]

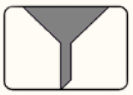
- Metal in the form of iron ore
- Metal in the form of non-ferrous metal ore[43]
- Lime and cement

Overview of the mining and mineral sector's emissions in tonnes of carbon dioxide (tCO_2), which amount to 3.7 million tCO_2. The stated percentages refer to the share of the sector's total emissions.



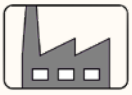
Mining (incl. transport) 194,000 tCO_2 (5.2%)

- By drilling and blasting, material is extracted from the bedrock which is then transported for processing. Internal transportation, machinery, and support processes such as heating and ventilation are included.
- Carbon dioxide emissions arise from diesel-powered machinery, the production of energy used for drilling, as well as for crushing and grinding ore (often electricity), ventilation, pumps, and the use of explosives.



Treatment 4,000 tCO_2 (0.1%)

- Contains a variety of processes such as enrichment, sorting, crushing, and grinding, but varies between company and sector.
- Almost all processing technology has switched to electric propulsion and, therefore, this step represents only a very minor part of the sector's total emissions.



Processing 3,402,000 tCO_2 (91.9%)

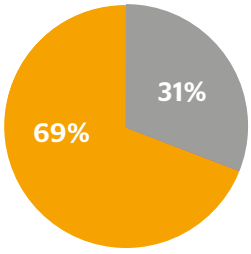
- Includes the production of iron ore pellets, copper, and other metals as well as limestone and cement.
- Carbon dioxide emissions originate primarily from fossil fuels used for heat in the processes. There are also processing emissions that occur as a result of the chemical transformation within the processing itself, for example during lime burning, metal separation, and pelletisation. Even chemicals used in production create emissions, and sometimes even during usage.

Recycling 101,000 tCO_2 (2.7%)

- Material recycling of batteries and electronic waste such as phones and computers.
- E-waste contains plastics that must be melted away to be separated in the process, which results in large carbon dioxide emissions.

> One example of the sector's climate work is LKAB's pellet production, where it has lowered its CO_2 emissions by 84 per cent since 1960.

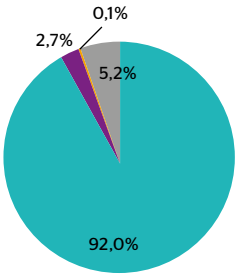
Carbon dioxide emissions (%) by sector



42 The activities involved in the mining and mineral sector involves some overlap with other sectors and roadmaps, mainly cement and iron and steel.

43 Non-ferrous metal ores include mainly lead, copper, gold, zinc, and silver.

Carbon dioxide emissions (%) per step in the value chain



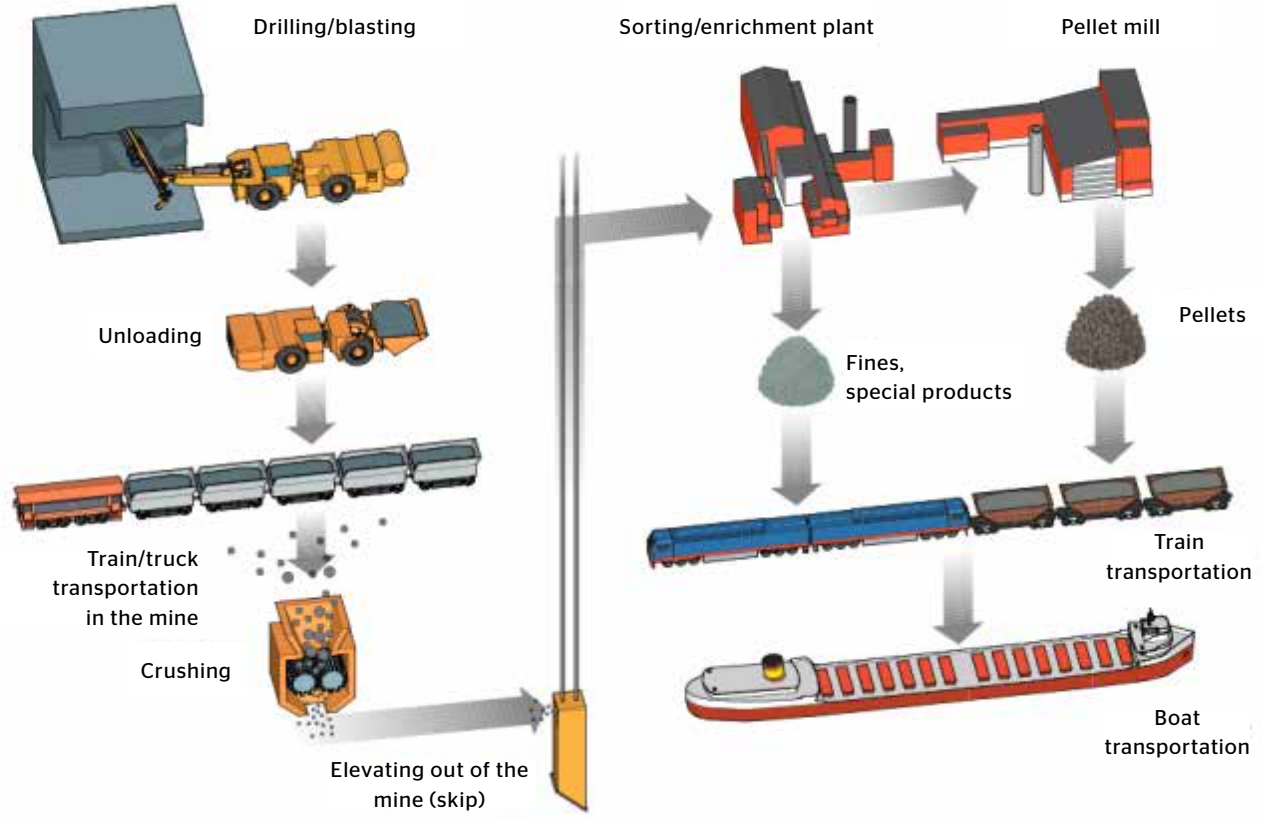
- Mining (including transportation)
- Treatment
- Processing
- Recycling

Factors affecting the climate footprint

The climate footprint can vary greatly between different mining operations depending on the prevailing conditions, what is being mined, and how far the operations have come in the green transition. The following factors particularly affect the levels of emissions:

- **Processing efficiency.** The overall efficiency of the production of a given amount of product has a major impact on emission levels. Opportunities for greater efficiencies arise at every stage. Optimised logistics within the mines can save substantial amounts of fuel for transportation, while efficient machinery results in lower energy consumption. The same opportunities also exist in refining ore into metals.
- **Energy with a low climate footprint.** A substantial proportion of energy use in mines consists of electricity, which powers drills, crushers, ventilation, and pumps, among other things, and which also powers several important refining processes (especially those based on electrolysis). The CO2 footprint of electricity varies markedly; for example, emissions per kilowatt hour (kWh) of electricity are almost twenty times higher in most Chinese provinces than in Sweden. Processes also vary depending on which energy source is used, with varying degrees of electrification or direct use of fossil fuels.
- **Processing emissions from the raw material.** When producing lime or cement, carbon dioxide is released from the limestone when it is heated to a high temperature. This type of processing emissions occurs regardless of the type of fuel used.
- **Climate-efficient raw materials.** The geological conditions can also affect levels of emissions. The clearest example is iron ore, where the amount of energy consumed in the production of pellets is much lower for some varieties (magnetite ore vs. hematite ore) and processes (pelletisation vs sinter) than for others.[44]

Overview of the entire process from mining to processing and transportation for LKAB

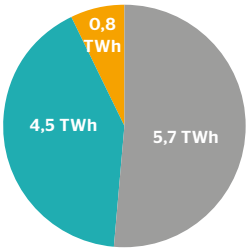


Note that the flowchart above is specific to LKAB and the value chain and transportation logistics appear different elsewhere in the sector.

44 Material Economics (2021) Klimatnyttan av svensk gruvnäring (English title: Climate benefits of Swedish mining).

To achieve the goal of fossil-free mining by 2035, the sector needs not only to switch to fossil-free transportation, but also replace the fossil fuels used for heating and ventilation.

Energy use[45]

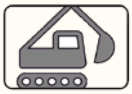


- Fossil fuels
- Biofuels
- Electricity

The sector's current energy consumption

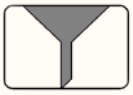
The sector's current total energy consumption amounts to approximately 11.1 TWh, which corresponds to approximately 2–3 per cent of Sweden's total energy consumption.

Processing is the most energy-intensive part of the value chain, which is explained by the fact that, in many cases, this stage requires extremely high temperatures and there currently exist no alternative fuels that can fully replace fossil fuels.



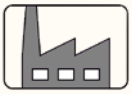
Mining (incl. transportation)

- Amounts to 16.9% of the sector's total energy use.
- Accounts for 9.4% of the sector's total fossil-based energy use.
- Electricity and diesel are used as the primary sources of energy. Diesel fuel is mainly used for transportation, but also for heating and ventilation. Some transportation is electrified.



Treatment

- Amounts to 21.5% of the sector's total energy use.
- Accounts for 0.2% of the sector's total fossil-based energy use.
- Treatment is often electricity intensive. Almost all treatment technologies have already switched to electricity.



Processing

- Amounts to 59.5% of the sector's total energy use.
- Accounts for 86.9% of the sector's total fossil-based energy use.
- Fossil fuels are used for the often extremely high temperatures required in processing. Some companies blend in biofuels or alternative fossil fuels such as used car tires and non-reusable raw materials.

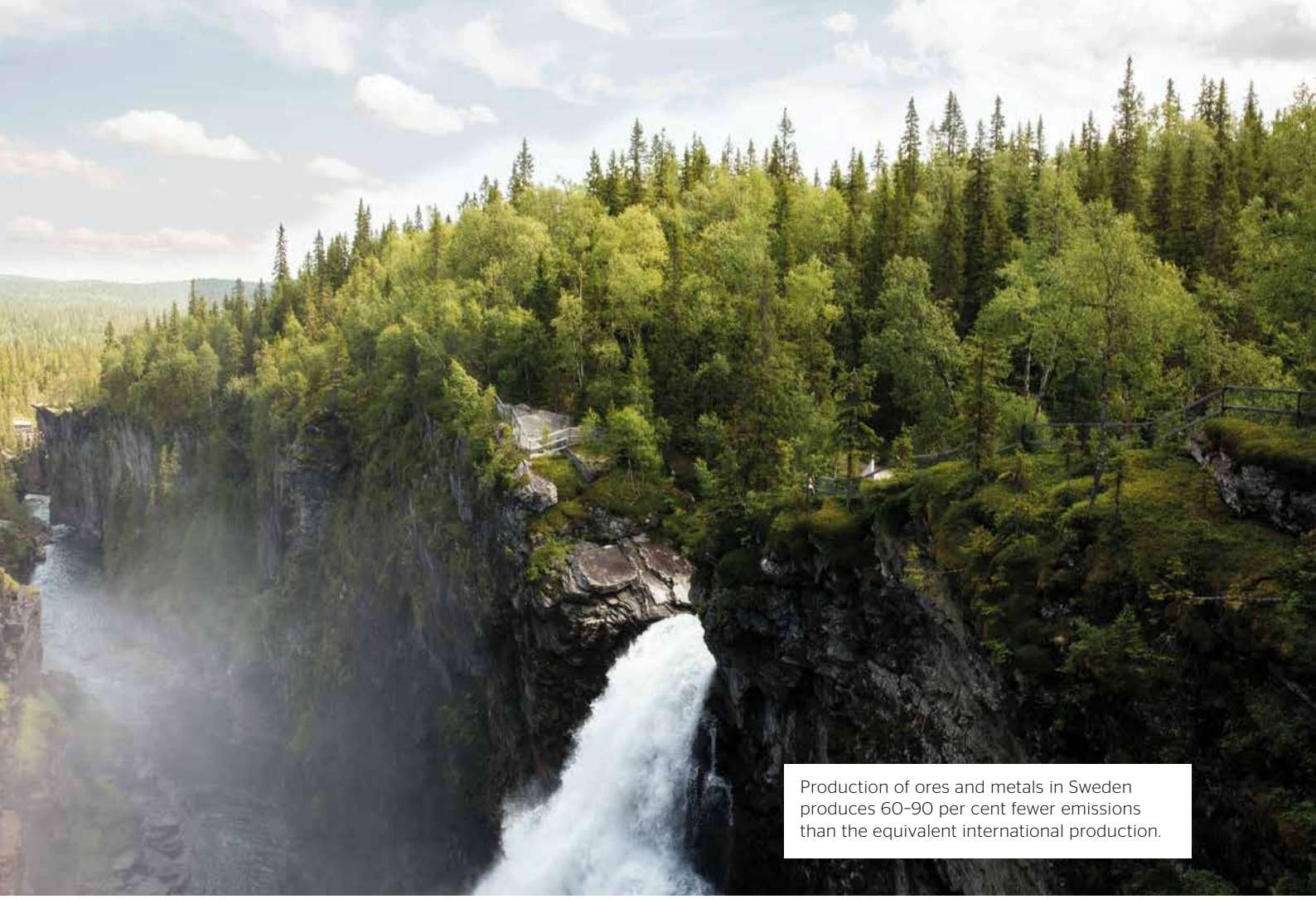
Recycling

- Amounts to 2.1% of the sector's total energy use.
- Accounts for 3.5% of the sector's total fossil-based energy use.

Our goal is crystal clear: by 2030, we want Sweden to be self-sufficient in climate-positive cement and for the Swedish construction sector to be able to build using climate-positive concrete. We will be able to achieve this once a full-scale CCS plant is in place at Cementa's plant in Slite in 2030 and we can then cut carbon dioxide emissions from cement production. But time is scarce and the issues to be tackled along the way include greatly strengthening our electricity grid and the efficient handling of environmental permits. I am convinced that Sweden has the will and the drive to take the lead in the green transition of the construction and civil engineering sector.

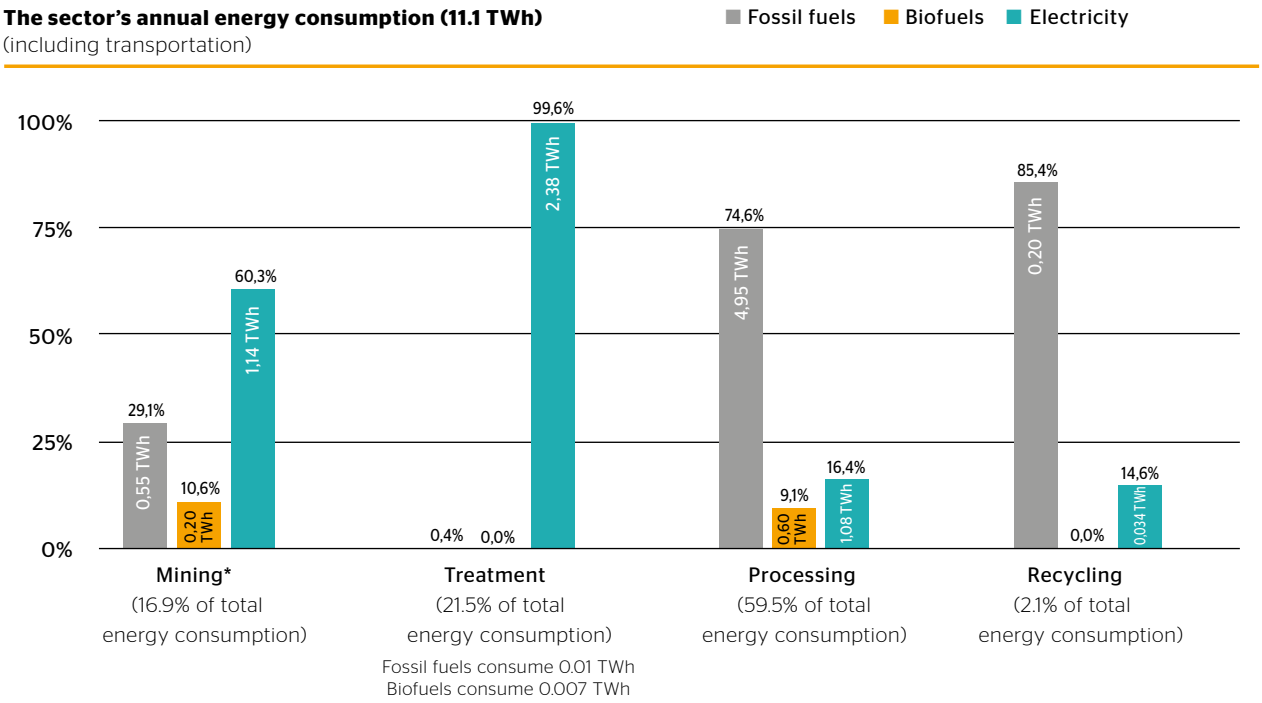
Karin Comstedt Webb, Executive Vice President HeidelbergMaterials Sweden

45 Today's electricity demand of 4.5 TWh, corresponds to approximately 3% of Sweden's total electricity use (140 TWh for 2021).



Production of ores and metals in Sweden produces 60–90 per cent fewer emissions than the equivalent international production.

The sector's annual energy consumption (11.1 TWh)
(including transportation)



An overview of the mining and mineral sector's annual energy consumption.[46] The mining and minerals sector's annual total energy consumption amounts to 11.1 TWh and consists of electricity, biofuels, and fossil fuels.

46 *Transportation accounts for approximately 170 GWh of the electricity used in mining.
*Transportation accounts for approximately 200 GWh of the biofuels used in mining, estimated on the basis of the reduction obligation calculated at the 2021 level.
*Transportation constitutes about 470 GWh of the fossil fuel used in mining.

The sector's climate goals

The Swedish mining and mineral industry play a key role in achieving Sweden's, Europe's, and the world's climate goals. High quality sustainably produced metals and minerals will be required for fossil-free energy systems, electrified transportation, climate-efficient construction etcetera. The mining, mineral, and metal sectors' ability to successfully manage the green transition is crucial for the other sectors following in the value chain to meet their own climate goals and implement their own climate roadmaps. These include the concrete, construction, electrical, automobile, and steel industries. A sustainable green transition requires sustainable metals and minerals.

Goal 2035: Fossil-free mining

To achieve the goal, there needs to be:

- Rapid increased electrification, automation, and digitalisation
- Phasing out of fossil fuels used for heating and ventilation
- Replacement of vehicles and work machines with electric and battery-powered alternatives

Challenges:

- High investment costs in electric vehicles
- Performance uncertainty as well as unstable electricity and fuel prices
- The complexity of mines makes charging infrastructure a challenge
- Lack of fossil-free explosives on the market

Goal 2045: Climate-neutral processes and fossil-free energy use

To achieve the goal, there needs to be:

- Developments in new processing
- New processes such as battery development, CCS and CCU, hydrogen production and storage
- Greater efficiency in processes
- Major technological and system developments and gains and as well as more inter-sector connections

Challenges:

- Stable access to electricity at competitive cost
- Development of fossil-free chemicals
- High investment costs for the transition

> Quote Sweden is to be one of the world's first fossil-free welfare nations.

Goal 2035: Fossil-free mining[47]

By 2035, the sector's goal is for mining in Sweden to be fossil-free, including transportation. Reaching fossil-free mining primarily concerns switching to fossil-free transportation, as well as automation and digitalisation and replacing fossil fuels used in heating and ventilation.

This is needed to achieve the goal

Achieving the goal requires increased electrification, automation, and digitalisation in the mines as well as replacing the fossil fuels used for heating and ventilation. In addition to reducing the sector's impact on the environment, the working environment (health and safety) will improve as a result of the transition, likewise there will be fewer exhaust fumes emitted and less demand for energy used for ventilation. Systems for so-called smart ventilation can save almost 55 per cent of the energy costs connected to ventilation in underground mines.[48]

Higher demand for electricity and biofuels

By 2035, the need for biofuels in mining is forecast to decrease by over a half[49], yet the demand for electricity will increase more than eightfold.[50]

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47 The calculations in this section are based on Sweco (2021): Underlagsrapport klimatfärdplan gruv och mineralbranschen, (English title: Background report for the climate roadmap mining and mineral industry), unless otherwise stated.

48 According to calculations made in the mining sector's first climate roadmap.

49 Metal (including iron ore) accounts for approximately 93% and lime & cement approximately 7% of the biofuel demand. Transportation accounts for approximately 43% of the demand for biofuels.

50 Metal (including iron ore) accounts for approximately 98% and lime & cement for around 2% of the demand for electricity. Transport accounts for around 19% of the demand for electricity.

Fossil-free transportation

Companies in the sector have invested in electrically powered conveyor belts (where possible), trains, electric trucks and, to some extent, in mining machinery. Currently, the fuel used for mining machinery is primarily electricity for drilling and, to an extent, for loading, however diesel is used for transportation.[51] The timing of the transition to fossil-free transportation varies from company to company, as does the choice between electricity and biofuels. The larger companies in the sector will be at the forefront, partly because their transition is more extensive and will take longer, and partly due to the required innovations and large investments which represent a greater challenge for the smaller companies.

Boliden's conversion to electrified mining trucks in Aitik

What: Conversion of trucks from diesel to electric in Boliden's Aitik mine. Boliden's large-scale production in Aitik – with its optimised mining methods, high degree of automation and partly electrified conveyor belts and trucks – make Aitik the world's most productive open-pit copper mine.

When: In progress

Cost: Total cost of the project is expected to be approximately SEK 240 million.

Changes in energy use: Reduce energy consumption by two-thirds for trucks, which corresponds to 51 GWh per year.

Reduced emissions: Boliden plans to reduce its greenhouse gas emissions by 40 per cent by 2030 compared with 2012. This will result in a reduction in emissions of 10,618 tCO_2 per year. Boliden has an electric trolley system in Aitik that aims to transport the majority of the approximately 70 million tonnes of rock transported annually in the open pit. This should be able to operate completely without fossil fuels and, thereby, reduce CO_2 emissions by 80 per cent and diesel consumption by 30–50 per cent compared to the previous system.[52]

> By 2035, the need for biofuels in mining is forecast to decrease by over a half, yet the demand for electricity will increase more than eightfold.

51 The reason for this is that electricity used in mining machines has generally been powered by connecting to the electricity network (i.e., not via battery) while diesel has been used when transporting mining machinery.

52 Swedish mining innovation (2019): First finalist in Swedish Mining Innovation Award 2019 – The group behind Boliden's Electric Trolley solution has succeeded in electrifying one of Sweden's largest diesel consumers.

Challenges

Transportation, both above and below ground, is the biggest challenge in reaching the target as it accounts for almost 90 per cent of the carbon dioxide emissions from mining. At present, diesel is used as the primary fuel. The majority of the sector plans to invest in the full-scale electrification of mining, while a few companies see biofuels or a combination of electric power and bioenergy as a solution. As mining companies operate in a global market, with global prices, it is important that the transition is feasible whilst maintaining competitiveness.

High investment costs for electric vehicles

The technological shift is at an early stage due to the required high investment costs. Electric vehicles are twice the cost of their diesel equivalents. In addition, battery-powered vehicles are heavier and can handle less load. However, the challenge is expected to be continually met over time due to technological developments in terms of reduced investment costs and improved battery capacity.

Performance uncertainty and unstable electricity and fuel prices

Uncertainty concerning performance and unstable fuel prices represent significant challenges. This is intricately connected to the geographical challenges of the large surface areas and difficult terrain mines face, which also pose challenges in terms of the need for fuel supply infrastructure.

- Today, however, HVO represents approximately 10–15 per cent higher fuel costs compared to diesel. One obstacle to the mining and mineral sector switching to vegetable-based biofuels, like HVO, is their reduced performance in cold climates as many Swedish mines are located in an Arctic climate. In addition, securing the availability of sustainably classified bioenergy is an important challenge as is the long-term competitive price of biofuels.
- As the entire transition is based on the shift from fossil energy sources to electricity, the availability of reliable and competitively priced electricity is the main challenge for maintaining competitiveness going forward.

The complexity of mines makes power charging infrastructure a challenge

Electric vehicles need to be charged and this requires connection to the power grid, which represents a challenge given the complexity and variety of the mines and makes stationary charging stations a particular challenge. For permanent routes, electrified conveyor belts can be a solution, however large parts of the mines remains.. The logistical challenge requires the development of charging infrastructure going hand-in-hand with both digitalisation and automation to design optimised and efficient systems. Therefore, multidisciplinary cooperation between technology suppliers, fuel suppliers, energy companies, vehicle developers, software developers, and mining companies is needed to ensure the transport solutions meet the future demands and climate standards.

Lack of fossil-free explosives on the market

Becoming completely fossil-free will additionally require the research and development of completely new solutions. For example, the development of safe, equally effective fossil-free explosives is needed. Such a product cannot, at present, be found on the market.

> Together, society, authorities, and industry create the conditions for achieving the sustainable transformation that is required. At Epiroc, we will continue to invest in R&D and innovation as enablers for the transformation and are, therefore, dependent on political decisions that ensure clear and long-term guidelines, competence supply, and sustainable climate for development.
>
> Anders Hedqvist, Head of Strategic Projects, Epiroc Underground Division

Kaunis Irons' goal of fossil-free mining by 2025

At its mine in Pajala, Kaunis Iron mines and refines around two million tonnes of iron ore concentrate annually. The company plans to operate a completely fossil-free mine by 2025. The majority of the processes are already electrified and, as such, near fossil-free, but the mining machinery and transportation still produce carbon emissions.

When: The company has taken a first step in the electrification of its transportation and in 2021 tested the use of battery-powered trucks together with Volvo Trucks, Vattenfall, and ABB, among others. By 2025, all transportation is planned to be fossil-free in some way.

How: The plan is for all machinery and transportation to be powered by electricity (either by cable or batteries) or hydrogen where appropriate. Electrically powered excavators are already in operation in the mine, and in the next step, other machinery and mining trucks are to be converted from diesel to electricity. During the transition period, other fossil-free fuels may be used.

Change in CO_2 emissions: Over 6,000 tonnes of ore are transported daily by trucks from the mine in Kaunisvaara to Pitkäjärvi, a distance of 160 km, before it is transferred onto trains. This accounts for about 40 per cent of Kaunis Iron's total carbon dioxide emissions.

Goal 2045: Climate-neutral processes and fossil-free energy use[53]

By 2045, the mining and mineral sector's goal is to have climate-neutral processes and fossil-free energy use. This means that emissions throughout the sector's value chain will be reduced by 100 per cent through changes in fuel usage, processes, or complementary measures.

This is needed to reach the goal

The sector's electricity needs will grow significantly as a result of the rapid technological developments underway in electrification, hydrogen reduction, and CCS (carbon capture and storage), which are all necessary steps in reaching the goal by 2045.

Technological developments such as CCS and CCU

In order to avoid the processing emissions from, in particular, the cement and the lime industry being released into the atmosphere, the development and expansion of large-scale commercial solutions are needed to capture carbon dioxide to use in industrial processes (CCU) and to capture and store carbon dioxide geologically (CCS). CCS is an energy-intensive technology in itself and requires substantial amounts of electricity.

Hydrogen and storage possibilities

Fossil-free hydrogen is an enabler for the sector's successful green transition and will be important in achieving the goal of fossil-free operations. Investments are needed both in terms of hydrogen production and infrastructure as well as in storage facilities. Hydrogen produced from fossil-free electricity is planned to be used in the reduction process used in iron production, amongst others.

Challenges

The processing stages are by far the most emissions- and energy intensive in the value chain. As these stages require extremely high temperatures in many cases, there are presently no alternative fuels able to fully replace the fossil fuels currently in use. Some companies do, however, blend in biofuels or alternative fossil fuels to some extent.

53 The calculations in this section are based on Sweco (2021) Underlagsrapport klimatfärdplan gruv och mineralbranschen, (English title: Background report Climate Roadmap for the mining and mineral industry), unless otherwise stated.

Copper.
Today, 65 per cent of all copper produced in the world is used to produce and conduct electricity. Renewable energy sources such as solar, wind, and hydropower require substantial amounts of copper to generate electricity and to transmit it great distances. Therefore, the availability of copper is one of the most crucial factors for an efficient clean energy transition.

Source: Boliden (retrieved 2022): Products Copper.

Access to fossil-free electricity at competitive cost
Since the sector's green transition is based on a substantially increased demand for electricity, a competitive energy cost and a stable supply of fossil-free electricity are crucial requirements for the sector's companies to be able to transition and implement the commitments summarised in the roadmap, as well as for Sweden to be able to maintain a competitive mining and mineral industry.

Process emissions from the raw materials
In addition to emissions from the fossil fuels used in processing, there are also emissions that occur as a result of the chemical transformation in the processing itself, for example during lime burning, metal separation, and pelletisation. In the production of limestone or cement, carbon dioxide is released from limestone when it is heated to a high temperature. These type of emissions from processing occur regardless of the type of fuel used.

Reducing the energy intensity per product unit
Reducing the energy intensity per product unit is an important part of the transition work and, additionally, results in reduced energy costs. For increased and improved efficiency, the sector is calling for more research and innovation.

Development of fossil-free chemicals
Achieving a fossil-free sector will also require research and development of completely new solutions. Chemicals and reducing agents used in enrichment and refining processes is a field which requires further research and innovations that will lead to the substances in use today being replaced by fossil-free chemicals. The iron and steel industry plans to replace coke with hydrogen as a reducing agent in processing, but further technological developments are required to ensure that all metals processed in Sweden are completely fossil-free.

Zinc.
A thin layer of zinc, known as galvanising, extends the life of steel structures by counteracting rust for 50 to 100 years. This means that the consumption of iron ore and substantial amounts of carbon dioxide emissions can be reduced, and society's investments in infrastructure become more long-lasting. Over 60 per cent of the zinc consumed annually in the world is used for galvanising. Therefore, zinc is important for the sustainable development of society.

Source: Boliden (retrieved 2022): Products Zinc.

High investment costs for the green transition
Energy is a significant cost item for the mining and mineral sector and currently represents around 15 per cent of total costs.[54] Reaching the target by 2045 involves extensive technological developments which will require a lot of capital. For the mining and mineral sector, as for all primary industry, a long-term perspective and a degree of security are required in the implementation of large investments, both in terms of capital costs and energy prices.[55]

A climate-positive cement plant

What: Through the capture and storage of the plant's total carbon dioxide emissions, Cementa's plant at Slite, Gotland will be converted to become climate-positive by achieving negative emissions.
When: Scheduled for completion by 2030.
Cost: The project is expected to cost approximately SEK 10 billion.
Change in electricity use: The CCS plant is estimated to consume 1.5 TWh of electricity per year.
Reduced emissions: The result will be a reduction in emissions annually of approximately 1.8 million tCO_2. This alone will reduce Sweden's total carbon dioxide emissions by three per cent.

54 The proportion varies depending on the size and operations of the different companies, the figure of 15% is a weighted average based on information from Svemin's member companies.
55 Sweco (2021): Underlagsrapport klimatfärdplan gruv och mineralbranschen, (English title: Background report climate roadmap the mining and mineral sector).

The world's first low carbon copper and zinc from Boliden

- Boliden, the third largest copper producer in Europe[56], has started producing both the world's first low carbon copper and first recycled copper. The products have a climate footprint of less than 1.5kg CO2eq/kg copper, which is less than half the global average for copper production.
- Boliden, presently the sixth largest zinc producer in the world, has started producing low carbon zinc. Boliden's Low-Carbon zinc has a carbon footprint of 1 tonne of CO2eq/tonne zinc, less than half the global average for zinc production of 2.5 tonnes of CO2eq/tonne of zinc.

LKAB's investment in fossil-free sponge iron with the help of hydrogen

Sweden's current iron exports are mainly in the form of iron ore pellets. The iron ore is then used at steelworks for the production of iron and steel. The processing produces high emissions. In the main production process, coke (produced from coal) is used to separate the iron from oxygen in a blast furnace. Carbon dioxide is then formed as a chemical by-product at a rate of two tonnes of CO_2 per tonne of metal produced.

LKAB's goal is to refine the iron ore further into iron using an alternative, so-called direct reduction process, where coal is replaced by hydrogen. The technology for this is being developed in the HYBRIT collaboration with Vattenfall and SSAB. By using fossil-free electricity to produce the hydrogen, CO_2 emissions from iron production can be eliminated.

What: Change the chemical reduction process of sponge iron using hydrogen (H_2), the residual product is then water (H_2O) instead of carbon dioxide (CO_2).

When: The initiative consists of several parts, and by 2026, the demonstration plant is expected to be in operation. The facility will then gradually expand until 2050.

Cost: About 400 billion SEK over 20 years in what could be Sweden's biggest ever industrial investment programme.

Changes in electricity use: The amount of electricity required for the hydrogen is as much as 70 TWh per year, corresponding to around half of today's total Swedish electricity production. All in all, this constitutes one of the largest ever proposed industrial investments in Sweden.

The CO2 gain would be of a corresponding enormous magnitude. Annually, as many as 40-50 million tonnes of CO_2 per year can be avoided by steelworks operators, compared to producing the same amount of iron through the blast furnace process that is currently used. This is approximately the equivalent of Sweden's total annual greenhouse gas emissions.

Sponge iron.

Hybrit – the world's first fossil-free steel

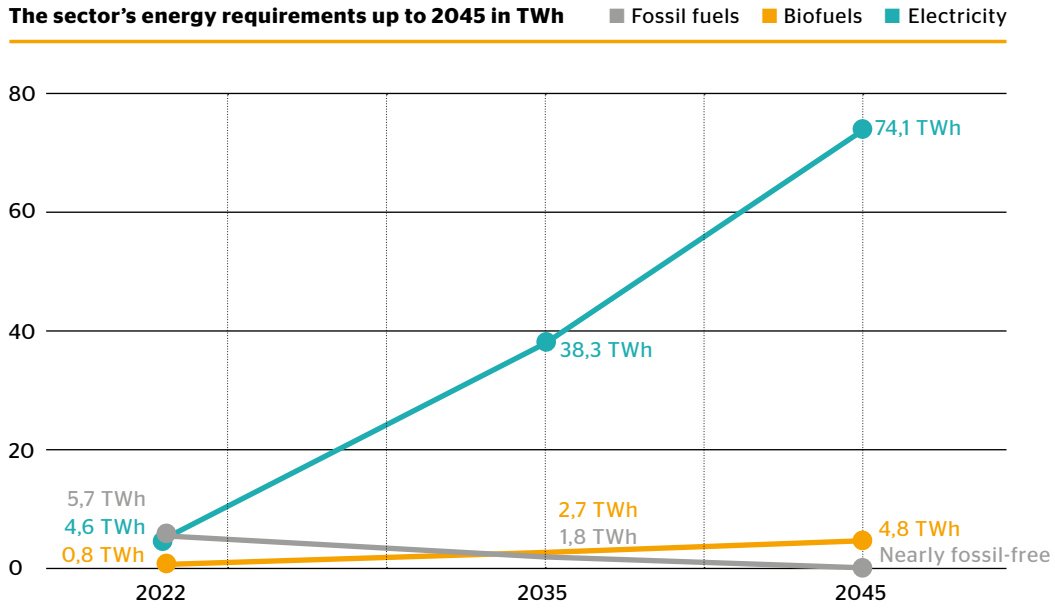
HYBRIT is a collaboration between LKAB, SSAB, and Vattenfall, which aims to create a completely fossil-free process for producing iron and steel. Instead of coal, hydrogen is used to reduce LKAB's iron ore to iron – the biggest technological development in the iron and steel industry for 1,000 years. The goal is to have a completely fossil-free process for steel production by 2035. The initiative has the potential to reduce carbon dioxide emissions by 10 per cent in Sweden and 7 per cent in Finland. The global steel industry currently accounts for 7 per cent of total global carbon dioxide emissions. Fossil-free iron and steel production using HYBRIT technology corresponding to the present production level for SSAB will require approximately 15–20 TWh electricity per year. Once completed, LKAB's operational restructuring will require a total of approximately 70 TWh of electricity per year. This will require more rapid and predictable permit processes for the expansion of Sweden's electricity grid.[57]

56 Boliden (retrieved 2022): Products Copper.
57 LKAB (retrieved 2022) Our transformation.

The sector's energy requirements in 2035 and 2045[58]

In relation to the expected electricity and biofuel requirements outlined in the first roadmap, which amounted to 1–2 TWh of electricity and 6–7.5 TWh of biofuels, the expected requirement for electricity by 2045 is now significantly higher, namely 73 TWh higher than stated in the previous climate roadmap. The single biggest difference is LKAB's investment in fossil-free sponge iron, which entails the company taking a giant step forward in the value chain compared to before. However, for biofuels the expected demand has decreased by approximately 2 TWh. However, it is worth noting that technological developments and new operations may further increase the need up to the given time.[59]

The sector's energy requirements up to 2045 in TWh



Compilation of the sector's expected electricity and biofuel needs by 2035 and 2045, and the increase in percentage compared to today ("today" is based on data from 2019–2020).

58 The calculations in this section are based on Sweco (2021) Underlagsrapport klimatfärdplan gruv och mineralbranschen (English title: Background report climate roadmap for the mining and mineral industry), unless otherwise stated.

59 Material Economics (2021) Klimatnyttan av svensk gruvnäring (English title: The climate benefits of the Swedish mining industry).

The sector's energy requirements by 2035

The sector's electricity needs until 2035 are expected to increase by 33.7 TWh, from today's 4.6 TWh to 38.3 TWh. 30 TWh of the expected increase is expected to be generated by the need for a hydrogen facility producing 220 ktonnes of hydrogen to meet the needs of LKAB's investment in fossil-free sponge iron.[60] The other 3.7 TWh will come from the remaining member companies' investments and energy transition work. For example, Cementa's CCS investment is expected to generate a need for 1.5 TWh of electricity by 2030.

The requirement for biofuel currently amounts to 0.8 TWh and is expected to increase by 1.9 TWh by 2035 to a total need of 2.7 TWh. The need for more energy includes the transition to fossil-free mining and investments in the transition of treatment, processing, and restoration by 2035. The energy use from treatment is expected to be fossil-free by 2035, as the amount of fossil fuels in use at present is already exceptionally low (about 0.4 per cent). However, since the treatment steps are energy-intensive and consist of around a fifth of the sector's total energy use, efficiency measures in the already electrified parts of the value chain are important from a resource-saving perspective. The total fossil energy use for the entire sector is expected to decrease by approximately 68 per cent by 2035 as a result of fossil-free mining, but mainly due to the green transition of processing and recycling.

LKAB will be the sector's largest consumer of electricity

As early as 2030, LKAB will require 20 TWh of electricity – that is the equivalent of today's total wind power production. In total, LKAB will need around 70 TWh once the entire hydrogen expansion is completed around 2050, which roughly corresponds to more than twice Denmark's total electricity use.[61]

The sector's energy requirements by 2045

74.1 TWh of electricity is expected to be required by 2045, which represents more than double the 2035 demand of 38.3 TWh and a 16-fold increase from today's 4.6 TWh. Despite the increased energy use, the sector forecasts the energy intensity per unit of volume produced will decrease in line with more efficient processes, increased production, and recycling. Of the expected electricity demand, LKAB's investment in fossil-free sponge iron in 2045 accounts for 64 TWh and Cementa's CCS investment 1.5 TWh. The remaining increase of 5.5 TWh is attributed to the other member companies' transition work developed in consultation with each company and not yet made public.

The need for biofuel currently amounts to 0.8 TWh and is expected to increase by 4.0 TWh to 4.8 TWh by 2045.

60 LKAB accounts for the largest share of the sector's electricity needs.
61 Indexmundi (retrieved 2022).

Iron ore pellets produce 90 per cent fewer emissions than international alternatives.

The climate benefits of Swedish mining[62]

The sector is currently undergoing major changes with plans for both the future of mining and metal production significantly different to how they have been carried out historically. In many respects, the Swedish mining and mineral sector is a pioneer in discovering climate-smart solutions. Tough regulatory requirements combined with high salary costs and cutting-edge research and innovation have led to the development of smart environmental solutions characterised by a high degree of automation, which Swedish companies also export globally. This section covers the companies in the mining and metals sector as well as equipment suppliers.[63]

Swedish mining is less emissions intensive than equivalent international production

The current production of ore and metals in Sweden is 60–90 per cent less emissions intensive than equivalent production internationally.

- Iron ore pellets production has 90 per cent lower emissions than international alternatives. The production of steel requires the further refining of iron concentrate into either iron pellets or sinter (a semi-molten and then solidified format for ore that allows it to be used in blast furnaces). The production of sinter is a process that requires vast amounts of energy that on average leads to emissions of around 200 kg CO2 per tonne produced. In Sweden, LKAB produces pellets that can be used instead of sinter in the production of steel. The emissions are only 25 kg per tonne produced, and, therefore, nearly 90 per cent lower.
- Producing one tonne of copper in Sweden emits 1.5 tonnes of CO2, which is only a third of the global average of 4.6 tonnes. Copper is produced by purifying copper concentrate through a number of stages, and then reducing it to pure copper metal by electrolysis. Globally, emissions from the production of one tonne of copper amount to around 4.6 tonnes of CO2 on average, of which around 40 per cent are direct emissions, and around 60 per cent are attributed to electricity use. The production of copper in Sweden gives rise to significantly lower emissions of around 1.5 tonnes of CO2 per tonne of copper.
- Producing one tonne of zinc in Sweden emits 1.4 tonnes of CO2, around 60 per cent less than the equivalent production internationally. Zinc is usually produced through an electrolysis process in which the zinc concentrate is heated, dissolved in acid, and then undergoes electrolysis to produce pure zinc metal. Emissions from zinc production globally average about 3.5 tonnes of CO2 per tonne of zinc, and the majority of these emissions are from the substantial amounts of electricity required. With Sweden's near fossil-free electricity system, emissions from zinc production in Sweden are around 60 per cent lower than global emissions.
- Rare earth elements can be produced in Sweden with an 80 per cent lower climate impact than is currently the case in China, and graphite with a 90 per cent lower impact. A calculation of the total climate benefit of the proposed production estimates it represents 2.4 million tonnes of CO2 per year, an increase of almost 40 per cent from today's estimated climate benefit (see the section on climate benefit below).

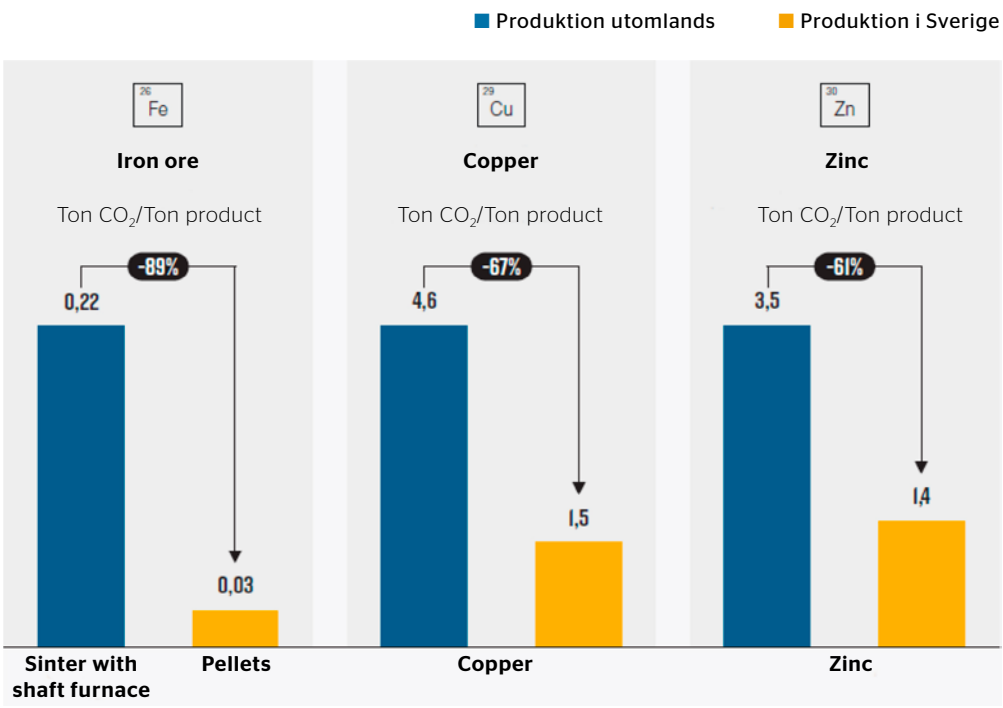
Factors accounting for Swedish production's low climate footprint

Sweden's low emissions can be explained by the availability of favourable raw materials and almost completely fossil-free electricity in combination with the fact that Swedish mining has made major investments in climate-smart technology, efficient processes, and electrification of both transportation and processing, which together has led to significantly lower emissions per tonne of product than the global average:

62 The calculations in this section are based on Material Economics (2021). Klimatnyttan av svensk gruvnäring (English title: The climate benefit of the Swedish mining industry), unless otherwise stated.
63 Lime and cement are not included.

- The fact that Swedish electricity is virtually fossil-free means that mining and metal production can operate with a low CO2 footprint. In addition, the historically abundant supply of competitively priced electricity has led to choosing processes that use a lot of electricity instead of fossil fuels, including within the refining stage.
- The close cooperation between mining sector companies, metal producers, machine suppliers, and research has, together, produced highly efficient mines that are widely regarded as among the most efficient in their class.
- Finally, the iron ore (magnetite ore) mined in Sweden has a high iron content, and chemical properties that make it require around 50 per cent lower energy input in the production of iron pellets than is required with most of the ore produced internationally. In addition, the pelletisation process itself is less carbon-intensive than the corresponding so-called sinter process used for the vast majority of global iron ore.[64]

The Swedish mining and metal sector has a significant lead in the green transition



Emissions from iron ore include mining, enrichment, and refining into iron ore products (pellets and sinters). Emissions for copper and zinc include mining (within Sweden), enrichment and refining into finished metal. Source: Material Economics (2022) Klimatnyttan av svensk gruvnäring (English title: The climate benefit of the Swedish mining industry).

LKAB's climate transition has already begun. We will significantly reduce the carbon dioxide emissions of the value chain from 2026. By 2050, emissions will be reduced by 40-50 million tonnes per year. Sweden has a unique opportunity to show the rest of the world that it is possible to abandon fossil fuel dependence even in industry – but to do so we need environmental permits and a secure supply of power. The political level must take its share of the responsibility, otherwise it will not be possible.

Stefan Savonen, Senior Vice President Energy & Climate, LKAB

64 Material Economics (2022) Klimatnyttan av svensk gruvnäring (English title: The climate benefit of the Swedish mining industry).

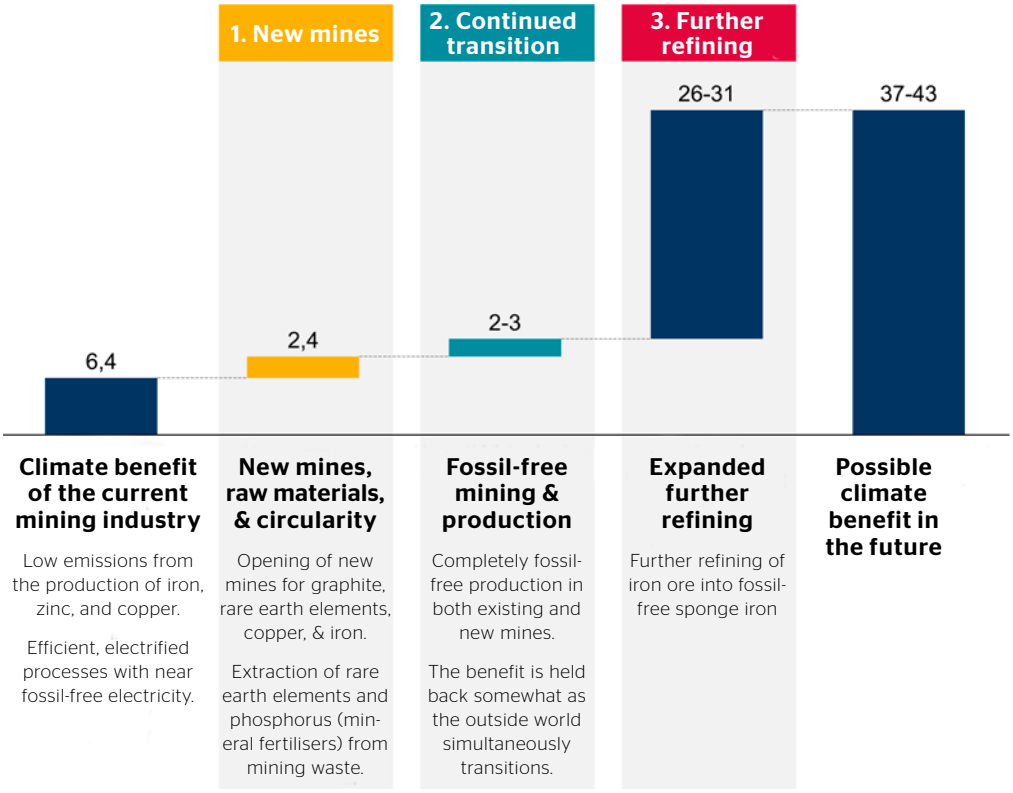
The climate benefit of Swedish mining has the potential to increase significantly

The climate benefit of the Swedish mining sector today is 6.4 million tonnes of CO2 – by 2045, the climate benefit could increase further by around 37-43 million tonnes of CO2 per year.

Instead of the approximately 9 million tonnes of emissions that occur from the average international production of the corresponding amount of metals and ore, production in Sweden emits 2.6 million tonnes of CO2 per year. This difference of 6.4 million tonnes of CO2 defines the sector's current climate benefit: the reduction in global emissions that Swedish production makes possible because emissions are already so much lower in Sweden. In comparison, this corresponds to almost 40 per cent of the total emissions from Swedish industry.

By 2045, the climate benefit could increase further by some 37-43 million tonnes of CO2 per year – if the plans that Swedish companies have put forward for new mines, more advanced and fossil-free processes, a new generation of mining machinery, and further refining using CO2-free energy and inputs can be implemented.

The climate benefit of the Swedish mining industry compared with production abroad
Million tonnes of CO_2 per year



New equipment – the electrification of mining machinery reduces emissions

Mining equipment is an area where Swedish companies have a major impact on the development of global technology as they account for the majority of the machinery used in underground mines globally and can drive further electrification and greater efficiencies within the sector. Mining machinery used for transportation and loading account for a large percentage of the fuels used in mining. A rough estimate of the total CO_2 emissions from diesel used in these machines (above and below ground) amount to as much as 70 Mt CO_2 per year globally.

For underground mines, battery-powered mining machines are a promising way to reduce emissions. Swedish mining equipment suppliers, such as Epiroc and Sandvik SMRT, which are world leaders with a market share of around 60 per cent for underground mines globally, offer a number of battery-powered models and have ambitious

investments to replace today's diesel-powered machines with electric alternatives. The companies expect to see rapid upscaling of these in the future. For example, Epiroc aims to reduce carbon dioxide emissions from machinery sold by 50 per cent between 2019-2030. The lifespan of this type of mining machinery is around five years, so the increased sales share of battery-powered models can have a fast effect on changing fuel use.

With the successful shift towards the electrification of mining machinery, whereby half of the mining machines sold by Swedish companies are electrified and where these are integrated efficiently for reduced ventilation, it is estimated that emissions of 10–14 Mt CO_2 annually can be avoided globally, partly from reduced diesel use, but above all from the reduced need for electricity used for ventilation in mines. According to one estimate, a system encompassing smart ventilation via electrification and digitalisation can reduce the need for ventilation by as much as 55 per cent. Electrification is also an important part of the increased digitalisation and autonomous operation of future mines, with corresponding opportunities for increased productivity.

The rapid electrification of mining machinery is dependent on several factors. Continuous innovation and development are needed to increase performance and improve economic competitiveness. Of equal importance is demonstrating that electrical machines meet the requirements of high productivity, fire safety, low costs, and more. As such, the initiatives underway in Sweden, including the SUM project, are of global importance in creating reference points allowing other firms to quickly adopt the new technology.

A new world standard in sustainable mining

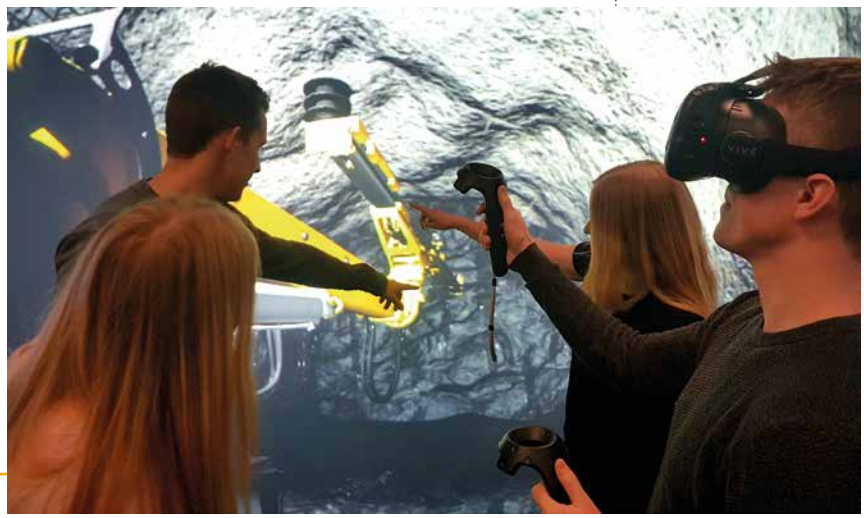
The sector has also come far in its digitalisation work to enable sustainable mining at greater depths. In the SUM (Sustainable Underground Mining) project, LKAB, ABB, Epiroc, Sandvik SMRT, and Combitech have joined forces with the shared goal of setting a new world standard for sustainable mining at great depths. The project will make cost-effective and carbon-free mining possible at a depth of around 2,000 metres and revolves around three principal areas: electrification, automation, and digitalisation.

Development of autonomous carbon-free mining processes

NEXGEN SIMS is an EU-funded cooperation project with mining companies, equipment and system suppliers, and universities, which aims to support new technologies, methodologies, and processes that will enable a more sustainable and efficient carbon-free mining. A key aspect of the project is to develop autonomous carbon-free mining processes. This includes the use of battery-electric mining equipment, full utilization of 5G for optimal connectivity and positioning, autonomous material handling, AI-driven traffic and process control as well as interaction between autonomous machines. The project also focuses on the miners of the future – the 'modern miner' – including safety, for example by developing autonomous mine inspection technology.

About the project

- Total budget of 16 million euros.
- Coordinated by Epiroc and project partners include the mining companies Boliden, Agnico Eagle Finland, KGHM Polska, K+S, and OZ Minerals; service and system suppliers Ericsson, Mobilaris MCE, AFRY, and KGHM Cuprum; and the universities Luleå University of Technology and RWTH Aachen.



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Appendix

The Climate Roadmap is based on two background reports produced on behalf of Svemin and its member companies.

Sweco – Underlagsrapport klimatfärdplan gruv och mineralbranschen (2022)

(English title: background report climate roadmap for the mining and mineral industry)

The climate roadmap for the mining and mineral sector produced by Sweco is based on official data as well as interviews and the collection of facts and figures from member companies. This background report has calculated the sector's current emissions and electricity requirements and forecast for the future with a focus on 2035 and 2045 in accordance with the climate and energy targets set and adopted by the sector.

The report can be read in its entirety at *https://www.svemin.se/klimatfardplan-2022/*

Material Economics – Klimatnyttan av svensk gruvnäring (2021)

(English title: The climate benefit of the Swedish mining industry)

This background report highlights the international climate effect of the Swedish mining industry based on current operations and future plans in comparison with international mining operations.

The report can be read in its entirety at *https://www.svemin.se/klimatfardplan-2022/*.

The sector's climate roadmaps

Interim Report I – roadmap for a competitive and fossil-free mining and mineral sector *https://www.svemin.se/fardplan-for-en-konkurrenskraftig-och-fossilfri-gruv-och-mineralnaring/*

Interim Report II – follow-up and complementary needs analysis *https://www.svemin.se/fardplan-for-en-konkurrenskraftig-och-fossilfri-gruv-och-mineralnaring/*

60	30	52	28	3	29	26	66	82	27
Nd	**Zn**	**Te**	**Ni**	**Li**	**Cu**	**Fe**	**Dy**	**Pb**	**Co**
Neodym	Zink	Tellur	Nickel	Litium	Koppar	Järn	Dysprosium	Bly	Kobolt

Svemin is the industry organization for mines, mineral and metal producers in Sweden. Svemin represents approximately 60 companies with roughly 15,000 employees in mineral production, exploration and technology. Member activities occur throughout Sweden. The exploration activities as well as the active metal mines are predominately located in northern Sweden and the area of Bergslagen in central Sweden, while the limestone deposits are mainly found on the island of Gotland.

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