ROAD MAP for Long-Term Competitiveness and a Fossil-Free Mining and Minerals Industry

SveMin

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Svemin is an industry association for mines and producers of minerals and metals in Sweden. Svemin represents around 40 companies with just over 13,000 employees working in production, prospecting and engineering. The member companies include mining companies, prospecting companies, limestone and cement companies and machinery and contracting companies. Member activities take place throughout the country. The mines are located in Northern Sweden and Bergslagen.

Foreword

Sweden – one of the world's first fossil free welfare nations

Sweden will be one of the world's first fossil free welfare nations. This is not just a vision but a firm reality, with several business sectors now presenting their roadmaps for fossil free competitiveness.Detta arbete är oerhört viktigt när utsläppsminskningarna av växthusgaser i världen går alldeles för långsamt för att hålla planetens temperaturökning under två grader.

This is crucial work in a time when greenhouse gas emissions are decreasing far too slowly to limit global warming to below 2 degrees Celsius. It is the task of the Fossil Free Sweden initiative to accelerate Sweden's climate mitigation and adaptation efforts, and it has therefore invited business sectors to produce their own roadmaps for fossil free competitiveness – and the response has been overwhelming. In the spring of 2018 nine roadmaps have been produced, and more will be launched during the autumn.

These roadmaps are unique initiatives. The fact that various corporate networks show their plans for becoming fossil free is certainly a good thing, but entire sectors drawing up their own roadmaps for being fossil free by 2045 is an initiative that brings hope for the future. It is not just the actual document that is important, but also the fact that it has entailed a farreaching process involving many other players through various workshops and seminars. Since there are so many roadmaps, producing them creates a momentum in Sweden, with more and more players taking steps towards being fossil free.

These roadmaps jointly make up a 'Jigsaw Puzzle of Sweden', showing how Sweden can become fossil free while welfare increases. The sectors are, however, owners of their own roadmaps' narratives, and of the policy demands necessary to enable them to realize their ambitions of the roadmaps. Fossil Free Sweden has worked with the sectors in various ways to support them in producing their roadmaps. This has included joint debate articles, participation in workshops, and occasionally giving concrete tips and advice. It should however be emphasised that the roadmaps are products of the sectors' inherent drive and commitment, and that the results and the various political suggestions highlighted are owned by the sectors themselves.

Through these roadmaps a Swedish national team for fossil free development has been created. It has come together to show others that another world is possible. When we demonstrate that a fossil free country is also the way to a better life, there will be a global race to leave the fossilbased society.

Svante Axelsson
National coordinator, Fossil Free Sweden

Fossilfritt Sverige

> Att hela branscher utvecklar egna färdplaner för fossilfrihet har inte skett någon annanstans i världen.

Summary

Mining and minerals – an important part of the solution

The Swedish mining and minerals sector will play an important part in a fossil-free future. The simultaneous transitions towards fossil-free energy and transport systems, a climate-smart built environment and increased recycling are all dependent on sustainably produced, high-quality metals and minerals, not least due to the demand for the metals and minerals required by modern batteries and infrastructure. The Swedish mining sector already generates benefits for the global fight against climate change via the export of climate- and environmentally smart products and equipment.

In order to seriously address the challenge of transitioning to fossil-free production, the mining and metals sector is taking at structured approach, producing a roadmap for sustainable, competitive and fossil-free mining and minerals over the course of 2018, within the framework of the Fossil-Free Sweden initiative.

The view from 2018 – taking stock of the situation today

Today the mining and minerals sector generates about 8% of Sweden's total CO2 emissions. Fossil fuels are used in multiple parts of the industry's value chain, and greenhouse gas emissions arise from transport and mining operations and in part from the processing of iron ore, metal ores, limestone and cement. Most of the industry's emissions come from production of iron ore pellets, smelting of ore into metals, and limestone and cement production, though emissions from the Swedish sector are low relative to global competitors. At the same time, many of the industry's processes and technologies are already fossil-free, especially in mining operations, and the transition towards fossil-free alternatives is already underway. The sector has made significant progress in switching from diesel- to electricity-powered technologies, and digitalization continues to drive optimization and efficiency, reducing overall energy and fuel requirements.

Processing of ore will require more to become fossil-free, and especially to deal with the process emissions that arise regardless of which fuel is used, for example when limestone is processed to lime and cement. Here development of existing technologies as well as a shift to new, currently undeployed technologies will be required. Biomass can replace some of the fossil fuels used today, but both fuel properties and supplies need development. Electric heating options can be a long-term solution but are immature technologically today. The iron- and steel industry is investing in hydrogen as a reducing agent in its HYBRIT project; research and development is likewise needed to identify process routes and system configurations for fossil-free production of other metals and minerals. Cementa has launched the initiative CemZero to investigate the conditions for electrifying cement production and eliminate CO2 emissions. Process emissions, however, will require a strategy for and development of technologies for CO2 separation and sequestration, geological storage of CO2 (CCS) and industrial re-use of CO2 (CCU).

Roadmap 2045 – this is what the journey looks like

In 2045 modern mining of ores and minerals is a sustainable complement to recycling in meeting global demand. Improved product designs and value chains for reuse and recycling have made it possible to recycle much of the metals and minerals in use. Yet recycling is not sufficient to meet demand from a growing global population and increased living standards. Primary production of metals and minerals is needed even beyond 2045, and global competitiveness remains essential for the Swedish industry, since only profitable firms are able to make the necessary investments.

One of the most important paths to fossil-free production is electrification. With help from biofuels in cases where electricity cannot be used operation of machines and internal transport in the mining sector become fossil-free as early as 2035. The transition to electricity has been driven primarily by technological progress and has mostly taken place via phasing out of old equipment and normal investment cycles. Competitive biofuels and/or hydrogen-based solutions have played a complementary role where

mine geography or shorter lifetimes and smaller-scale operations hinder deployment of electricity-based solutions. Automation and digitalization have decreased energy requirements by optimizing production and making vehicles more efficient. Infrastructure for charging and hydrogen fueling is in place and necessary investments in the electricity grid have been completed.

Sweden has established a unique, world-class CO2 -free system for processing iron ore. In part ore is processed by direct reduction using hydrogen. Pellets production continues as well, with process heat from CO2 -free energy, either biomass or indirect heating via electricity. Hydrogen gas production, direct reduction and pellets production have been co-located for optimal energy use. Processing of other metals is also CO2 -free. Lime and cement production likewise uses indirect heat from electricity and/or biomass, and process emissions are handled via CO2 separation and geological storage (CCS) or reuse (CCU), for example in methanol production or algae production. These investments have been expensive and have not been borne by individual companies – public and provide investments in technological progress have been essential. New pricing models have been introduced.

Critical conditions and barriers

The mining and minerals sector is optimistic that the transition will be a successful one. Yet the necessary development will require time and capital. Farsighted political decisions that promote the industry's global competitiveness will be central to achieving success, as will effective and reliable approval processes for new investments.

The industry is prepared to invest but barriers along the way need to be cleared. Here politics has a clear responsibility to maintain a long-term and holistic view.

The most important conditions where politics can make a difference are:

- Effective and reliable permitting so that new, necessary and climate-smart investments are possible
- A holistic view in political decisions that avoids (for example) policies that sub-optimize and harm the industry's competitiveness and ability to invest in fossil-free production
- Investment in research and development within fossil-free production processes and CCS, including test sites and upscaling
- Conditions for access to fossil-free electricity with a low total system cost and high realibility
- Strategic allocation of biomass and access to biofuels at competitive prices

The industry, the public sector and other actors need to work together to bear the cost of the transition, drive technological development and support the achievement of global and national climate goals.

1. The mining and minerals industry – an important part of the solution

Metals and minerals are crucial and irreplaceable building blocks in the development of society – both inside and outside Sweden. Metals and minerals are at the beginning of long, growing value chains and they are critical elements in infrastructure, communication equipment and sustainable energy systems – areas in which solar cells, wind power, rechargeable batteries and electronics require a supply of new raw materials.

In a future, modern, sustainable and more prosperous society metals and minerals will continue to be in demand, produced, sold and purchased. Agenda 2030 and the international and Swedish climate goals are dependent on new technologies, which in turn require a supply of metals and minerals.

The processes of extracting metals and mining industrial minerals must be sustainable. This means taking into consideration people – health, social and cultural aspects; the environment – emissions, waste management, after-treatment, natural value, energy and climate; and economics – social development, welfare, competitiveness, resource economy and a circular economy.

The mining and minerals industry is an important part of the climate transition solution and is helping to achieve the goal of a carbon-neutral society. It is also important to ensure that Sweden stays competitive in a global market. In several respects the Swedish mining and minerals industry, and the value chains associated with it, are at the forefront in terms of finding climate-smart and green solutions – innovative solutions that other areas of society can also benefit from. Tough legal requirements combined with high payroll costs, as well as cutting-edge research and innovation have resulted in smart solutions with a high degree of automation – solutions that Swedish companies are also exporting.

2. An industry-wide roadmap

To properly meet the challenge of conversion to fossil-free production, the mining and minerals industry is keen to ensure that the transition takes place in a structured way. In 2018 the industry therefore produced a road map within the framework of the Fossil-Free Sweden initiative. Svemin is leading this effort with the RISE research institute and in cooperation with member companies and other important players. The Road Map will be a tool to analyse and describe the technology, investments, strategies and systems today and what development could and should look like to ensure the industry will be part of a fossil-free society.

One objective in producing the Road Map is to identify the most important requirements, prioritised areas where investment can be made and also which obstacles are in the way of the industry becoming fossil-free by 2045. An important aspect is conveying this message to other actors in society who can impact the conditions for freedom from fossil fuels – i.e. politicians, public agencies, suppliers and customers.

3. Three sectors – one road map

The Road Map for a Fossil-Free Mining and Minerals Industry covers mines and mineral and metal producers in Sweden, i.e. mining and processing of ore and industrial minerals. To simplify the analysis and the approach to producing the road map, the industry is divided into three main sectors: i) iron ore, ii) other metal ore1 iii) lime and cement (see Figure 1).

> In a future, modern, sustainable and more prosperous society metals and minerals will continue to be in demand, produced, sold and purchased.

1 Today the main metals being refined are the following: gold (Au), silver (Ag), copper (Cu), lead (Pb), zinc (Zn) and tellurium (Te).

Swedish mining and minerals industry

- Iron ore deposits are mainly located in the far north of Sweden, while base metals and precious metals are mainly found in Skellefteфältet and Bergslagen
- The largest limestone deposits in Sweden are found in the island of Gotland.
- In Sweden today there are 14 iron ore and other metal ore mines in operation.[2]
- Sweden is the EU's largest mining nation with just over 90 percent of iron ore production and around 40 percent of lead and zinc production, as well as 9 percent of copper and 23 percent of gold.[2]
- Mines take up around 0.02 percent of Sweden's surface area; golf courses take up 0.07 percent.[2]
- The large mining and minerals companies in Sweden are LKAB, Boliden, Zinkgruvan, Cementa and Nordkalk.
- The Swedish mining cluster includes companies such as ABB, Sandvik, Atlas Copco and SSAB
- Mining companies employee almost 7,000 people in Sweden[3] – this can be multiplied by 4.9 for the total employment effect.[4]
- Swedish machinery suppliers deliver around 60 percent of the world's underground equipment. [5]
- The Swedish mining and minerals industry combined with the steel industry account for 10 percent of gross exports, totalling SEK 87 billion. [6]
- Swedish mines have a lost time injury frequency of 5.5, the lowest figure in basic industry.[7]

Some of the industry's operations and value chains are covered by or associated with other road maps within the framework of the Fossil-free Sweden initiative, including those of Cementa, the steel industry and the haulage industry. The industry has therefore chosen to limit this Road Map as shown in Figure 1. Internal transportation, equipment operation and support processes in actual mining areas, as well as today's production of iron ore pellets, lime burning and metal smelting plants are included. Most activities outside the dotted lines – current steel production, transport routes outside the mine boundaries and cement production – are instead covered by other road maps. Where future solutions require structural changes – such as the use of direct reduced iron using hydrogen gas, or CCS technology[8] in refining lime and cement – the Road Map takes these into consideration, but the reader is referred to the other, above-mentioned road maps and strategies where these are the primary solutions. This Road Map thus does not describe the HYBRIT project[9], CemZero[10] or Cementa's road map[11] in any detail. These are, however, important parts of the solution for the mining and minerals industry.

This document presents the results from the Road Map preparation process up to the end of April 2018 – i.e. the framework of the Road Map, the current situation and the most important investments and undertakings needed to achieve the fossil-free goal in 2045. The process going forward will include deeper analysis and producing the plan. A final version will be presented in autumn 2018. The aim is for the Road Map to live on and be updated from now until 2045.

Road map
A road map combines what we know about and have experience of today with the future we can envision. A road map should support the planning carried out in other contexts. It is thus not a plan that can be directly translated into something that each individual member company undertakes to execute. The Road Map is a plan consisting of objectives and milestones for companies to navigate based on the work they are doing that is specific to their own operations.

2 SGU, 2017. *Bergverksstatistik 2016*. Periodic publications 2017:1
3 6,700 people in 2016, including all subcontractors
4 Ernst&Young, 2016. Employment multiplier of 4.9 – i.e. the number of mining jobs x 4.9 indicates the total number of jobs generated by mining operations
5 Svemin, 2012. *Gruvbranschen – en tillväxtmotor för Sverige* (The mining industry – a growth engine for Sweden) September 2012
6 SCB, 2017. Statistics for product groups 67, 68 and 281. Note that these numbers to not include mine-related engineering products
7 Basic industry's reported LTI statistics 2016. LTI = number of occupational injuries with a loss of work time per million hours worked
8 CCS = carbon capture and storage
9 HYBRIT: LKAB, SSAB and Vattenfall have launched a development project with an end-goal of hydrogen-based iron production Using direct reduction, hydrogen can be used to separate iron from oxygen without using coal and without carbon emissions. Read more about the project at www.hybritdevelopment.com
10 CemZero: preliminary study of electrified cement production with the goal of zero carbon emissions by 2030. https://corporate.vattenfall.se/press-och-media/pressmeddelanden/2017/vattenfall-och-cementa-satsar-pa-nollutslapp/
11 Cementa is producing a road map for its own fossil-free efforts. Read more about this in "Färdplan för fossilfri cement och betong" www.cementa.se/sv/hallbarhet

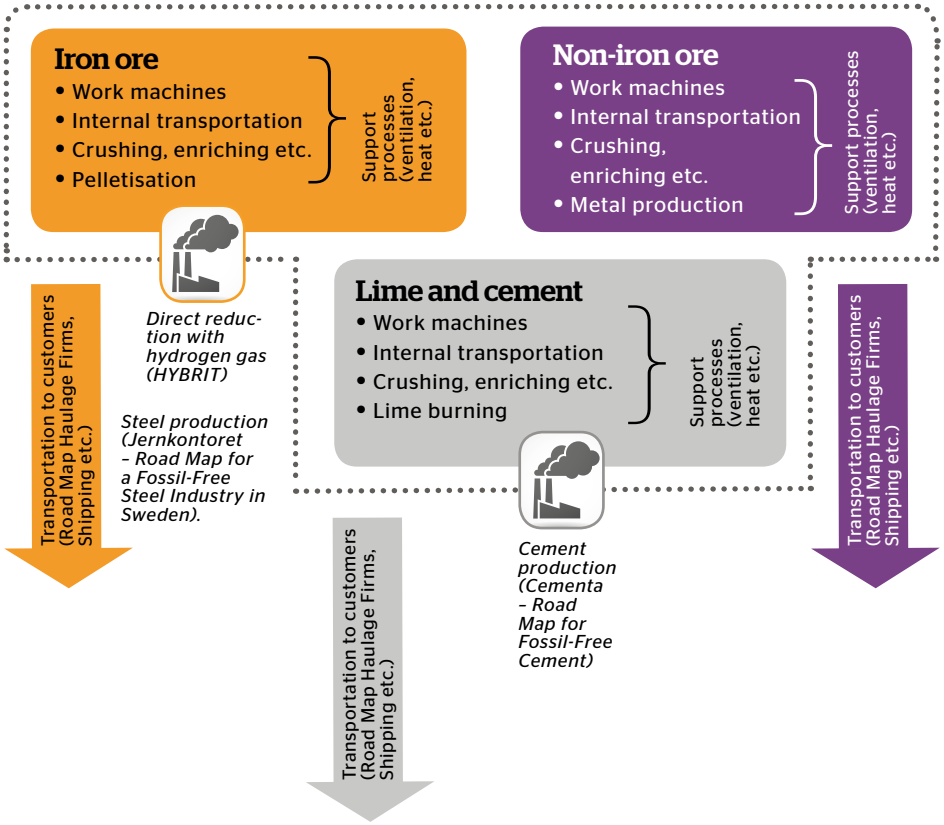

Figure 1. The industry can be divided into three main sectors: iron ore, other metal ore, and lime and cement. The dotted line illustrates the boundary and where other road maps apply

4. Status report – fossil fuel use and emissions today

Today carbon emissions are generated in several parts of the mining and minerals industry value chain. The mining and minerals industry accounts for around 7–9 percent of Sweden's total carbon emissions. Emissions in the three sectors break down as follows: 1 percent from iron ore production, less than 1 percent from metal production and around 6 percent from lime and cement production, as a percentage of Sweden's total emissions.[12] Emissions are generated from the use of fuels in transportation and processes. It is, however, important to point out that these emission levels are very low in a global comparison.[13]

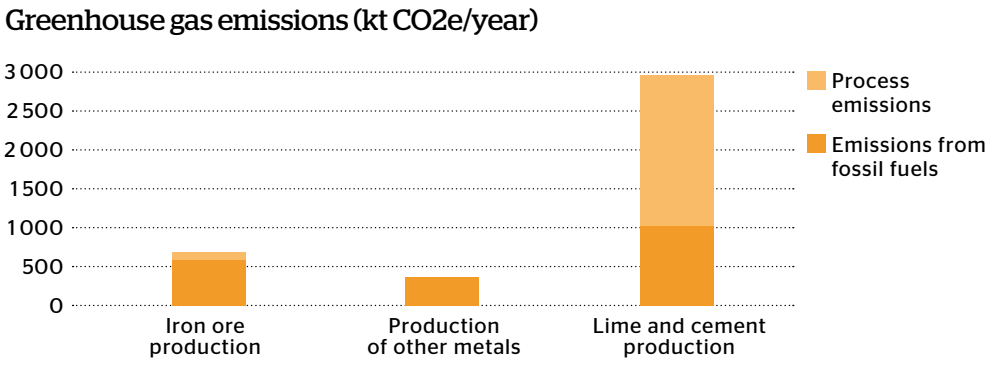

Figure 2. Total greenhouse gas emissions in thousands of tons of CO2 equivalents in 2016 from the industry's three sectors: iron ore, other metal ore and lime and cement ((Naturvårdsverket, 2017) and (LKAB, 2016)).

12 Based on iron ore production around 1 percent, metal production less than 1 percent and lime and cement production around 6 percent of Sweden's total greenhouse gas emissions, including international transportation but excluding LULUCF. Source: Swedish Environmental Protection Agency, SCB and LKAB, data from 2016.

13 LKAB and Boliden's websites, 2018.

Fossil fuels are used in most parts of the mining and minerals industry's value chain. Fossil fuels are used for machinery operation and internal transportation to some extent. Diesel engines are used in vehicles and certain heavy machinery for mining, loading, etc. The mines are to some extent heated using fossil fuels. Several processes and technologies in the industry are already fossil-free, above all in actual mining operations.

Today's processes for grinding, crushing and enriching are, for example, essentially 100 percent electric powered. In mining there is an ongoing process of electrification of many applications where there are technical, financial and/or safety benefits to gain.[14] Electric-powered processes are better for the environment due to reduced exhaust gases at the site. Also, less energy is needed for ventilation. It is estimated that a so-called smart ventilation system could save almost 55 percent of the energy costs associated with ventilating underground mines.

The industry has made significant progress in replacing diesel-fuelled machinery with electric-powered equipment, and digitalisation is driving efficiency improvement and optimisation, which is reducing overall energy and fuel consumption. More and more mining trucks are being electrified or replaced by conveyor belts wherever possible. Other concrete examples of this are the planned and ongoing electrification at the Aitik mine – Sweden's largest open-pit mine – and electrified vehicles in the mine in Kiruna. In Zinkgruvan there is a project under way to introduce eco-driving for mine vehicles, involving educating drivers and programming the vehicles. Another example is Cementa's active steps to optimise flows, shorten routes and reduce bumps and slopes for less uphill driving. The plan is for Boliden's mine due to open in Laver, to be 100-percent electrified from the start.

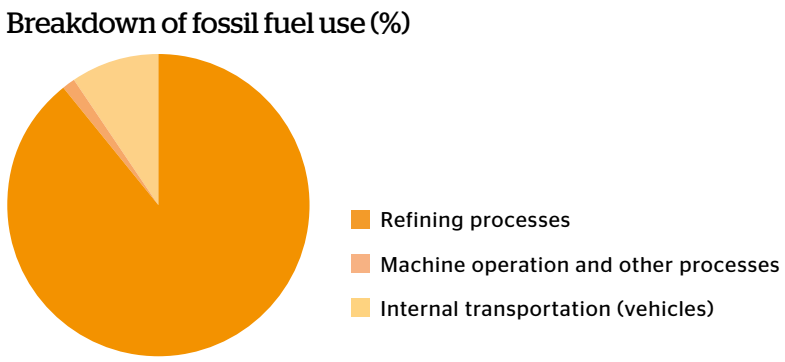

Figure 3. The approximate percentage of fossil use in the Swedish mining and minerals industry in three areas: vehicles for internal transportation, refining processes, and machinery operation and other processes. (Estimates based on discussions with member companies as well as data from Naturvårdsverket, 2016).

Emissions from iron ore pelletisation, metal production and limestone and cement production processes are at very low levels in a global perspective but account for a significant amount of carbon emissions in Sweden. The low climate footprint in a global comparison is the result of efficient processes, the inherent properties of the ore and access to electricity with a low climate footprint. Carbon emissions from lime and cement production consist largely (around 65 percent) of so-called process emissions, where CO2 does not come from fuel combustion but from the actual mineral calcium carbonate (CaCO3) which is released in connection with heating in the refining processes, and is unavoidable. When iron ore pellets are produced carbon emissions come from fossil fuel consumption in pellet agglomeration.

The industry is looking into the possibility of using biofuel as a heat source and as an additive, but further development is needed. The use of indirect heating generated by electricity and of alternative reducing agents such as hydrogen gas is still at an early stage and extensive research and development is needed. To address the process-related

14 Today Sweden's electricity mix is not entirely fossil-free. The road map is based on the assumption that electricity will eventually be fossil-free and that electrification is a fossil-free solution. The industry cannot control the electricity production mix, but several companies are already buying certificates that are equivalent to production from fossil-free sources.

emissions that arise – irrespective of the type of fuel used – for example when limestone is refined to produce lime or cement, more research and development work is needed. HYBRIT and CemZero are important initiatives in this area.

Metals recycling through extraction from scrap electronics and lead batteries is important in the transition to a circular economy. When lead batteries are recycled the battery components are dismantled and the plastic recycled. Scrap electronics are dismantled and plastic and other materials are separated to the greatest extent possible. However, in some of the residual parts the metal and plastic are very closely interconnected, e.g. in a circuit board, which means that some melting of fossil plastic is needed. In the future new product design criteria and the ability to further dismantle and separate materials in the devices will reduce the need to melt plastic.

A general analysis of the current situation has been made with respect to activities that use fossil fuel in the industry today, which alternative technologies and solutions are known now and the status of ongoing initiatives, investments, testing or research (see Figure 4). The analysis is a summary of a workshop exercise in March 2018 as part of the process of producing the road map.[15]

Activities (current situation)	Fossil fuel use (current situation)	Alternative technologies	Ongoing initiatives/ research in the industry
Internal transportation	Vehicles	Electric-powered (battery/cable/hybrid)	Investments
		Biofuels	Mixing according to reduction requirement
		Optimisation/automation	Investments
		Conveyor belt	Investments
Machinery operation (including support processes)	Heating	Optimering/automatisering	Investments
		Electric-powered	Investments
	Machinery operation, misc.	Biofuel**/climate-neutral heat carriers	Small-scale use (lime)/ development **
			Research
Pelletisation (iron ore)	Burning and refining	Climate-neutral heat carriers	Research
		Electricity	Research
Direct reduction* (iron ore)	Natural gas	Hydrogen gas and electricity	Research
Metal refining	Burning and refining	Biofuel/climate-neutral heat carriers	Research
		Electricity	Research
Lime burning and cement production	Burning and refining	Biofuel**/climate-neutral heat carriers	Mix commercial/ development
		Electricity	Research

Figure 4. Summary of the current status of activities in the industry where fossil fuels are used today, which alternative technologies the industry is considering and an evaluation of the status of the investments or research to find fossil-free solutions. *The investments are normal investments in connection with reinvestment activity or new facilities/plants.

The work of preparing the road map also included an exercise to make a general evaluation and simplified assessment of the potential to become fossil-free in the main areas where fossil fuels are used today. The evaluation was made based on four conversion factors: technology maturity for the various solutions; anticipated conversion time; investment costs for the fossil-free solution; and risks (such as technology risk or the risk of additional costs during operation). The exercise was carried out with the help of a so-called traffic light analysis tool and based on the knowledge and experience that exists today. The traffic light colours green, amber and red indicate the following: Green means "easier to implement"; amber "harder to implement" and red "hardest or more risky to implement." The evaluations of each conversion area based on today's perspective are summarised in Figure 5.

15 A workshop was held on 14 March 2018 as part of the process of producing the road map. The workshop was attended by around 20 individuals representing companies in the industry, e.g. mines, metal producers, mineral producers, technology suppliers, energy companies as well as public agencies, industry organisations and researchers.

Conversion factors				
Conversion area	Technology maturity	Conversion time	Investment costs	Risks (incl. costs)
Internal transportation				
Machinery operation (incl. support processes)				
Pelletisering (järnmalm)				
Direct reduction				
Metal refining				
Lime burning and cement production (fuel)				

Figure 5. Conversion factors by conversion area based on a general traffic light analysis with today's knowledge and technology level – where **green** means "easier to implement", **amber** "harder" and **red** "hardest/risks."

To summarise, the traffic light exercise indicated that, with respect to the *internal transportation and machinery operation* conversion areas, conversion to fossil-free operation by 2045 with a margin is considered a reasonable goal. The conversion is mainly expected to be implemented within the framework of planned investment cycles, e.g. by replacing vehicles and machinery that have reached the end of their useful life. It was also determined that the industry has made good progress in replacing diesel engines with electric ones – a trend that is expected to continue to accelerate. In internal fossil-fuelled transportation some biofuel will also come into the mix due to the reduction requirement. The industry is also constantly increasing automation and working on improving efficiency and optimisation to reduce overall energy and fuel consumption.

In the refining processes conversion area, the options are less mature than for *internal transportation and machinery operation* and the uncertainty is greater. LKAB's, SSAB's and Vattenfall's joint HYBRIT project has identified opportunities for conversion to direct reduced iron (DRI) with the help of hydrogen gas. This process is a carbon-free alternative to producing iron in a blast furnace where coal is the reducing agent. There is, however, great uncertainty surrounding the conversion of existing pellet plants. Progress in the conversion concepts for refining other metals and lime burning has not come as far. Here the development process is considered more risky as there is neither a clear idea of the costs nor any competitive alternatives. The industry is looking into the possibility of using biofuel as a heat source and reducing agent, but at this time there is no solution for commercial use.

5. The industry in 2045

The Swedish mining and minerals industry is contributing today and will continue to contribute to a fossil-free society beyond 2045. Achieving an industry free from fossil fuels must be put in context – the status of the global market, conditions within the EU, design of European policies, Sweden's infrastructure and the mining and minerals industry's operations are of course crucial factors to achieve conversion while maintaining global competitiveness. Here is a summary of a future scenario – a conceivable, desired situation in 2045 where conversion has been possible. This is a summary of discussions at a workshop within the road map process but does not represent the only conceivable future scenario. The visions and conclusions will probably need to be revised along the way.

Vision for 2045

By 2045 modern mining of ore and minerals in Sweden is sustainable for the long term and integrated with recycling processes to meet the global demand. Improved product design and value chains for re-use and recycling have enabled recycling of a very high percentage of metals and minerals. Recycling alone is, however, not sufficient to cover the global demand with a growing population and higher standard of living. Primary production of metals and minerals in Sweden will be needed for the foreseeable future, including beyond 2045.

In 2045 the market for the industry's products is driven to pursue further sustainable development. Electrification, energy conversion, digitalisation and climate adaptation are creating demand for sustainable metals and minerals. The world's largest nations have gradually united and agreed on production and consumption requirements, and they have reduced the advantages for products that impact the environment and climate. At the same time a prime market has emerged where manufacturing industries and their end-customers demand and are willing to pay for sustainable products with traceable content from mining to recycling. Sweden is the leading supplier of metals and minerals to this conscious market.

In 2045 an improved permit process is resulting in investments being made in environmental and climate-smart mines, where rare earth metals etc. are being extracted. The mining and minerals industry is still located where the natural resources are found – largely the same geographies as today. Iron ore is produced from deeper mines and mining companies are using the ore to a greater extent to produce lithium, cobalt, uranium, phosphorus and other metals and minerals etc. Recycling plays a large role in the material supply and the mining industry has continued to develop its role in extracting metals from scrap electronics etc. Greater recycling has increased the requirements with respect to the amount of primary raw materials in the mix. Here Sweden's high-quality production is a competitive advantage.

In 2045 Sweden's electricity production and electricity infrastructure have been strategically expanded to give access to fossil-free electricity at competitive prices. Wind power no longer creates any problematic fluctuations and there is sufficient storage capacity in reservoirs, and in hydrogen gas and battery storage downstream. Sweden has a surplus of (fossil-free) electricity and the mining and minerals industry plays a dynamic role by optimising operations and to some extent through its own electricity production and storage. Areas where facilities have been closed have gone through appropriate remediation. Wind parks have been established in some remediated sites and are contributing to the electricity supply.

In 2045 the industry's internal transportation and machinery operation have already been fossil-free for a decade and 95 to 100 percent of vehicles and machines are electrified. Biofuel and/or hydrogen gas are used for the remaining energy requirement where either complex ore geography or shorter operating times/ a smaller scale make electrification problematic. Automation and digitalisation have further reduced the energy requirement and resulted in more efficient vehicles and optimised vehicle use. Infrastructure for battery charging and hydrogen gas refuelling has been put in place and essential investments have been made in power grid solutions.

In 2045 Sweden has unique, world-class, carbon-free processes for iron ore refining. The iron ore reduction process uses hydrogen gas. Process heat needed for iron ore pelletisation comes from climate-neutral heat carriers or indirectly from electric furnaces. Hydrogen production, direct reduction and pelletisation all take place in the same place to achieve energy optimisation. Processing of other metals is also carbon-free. In lime burning and cement production indirect heat is used from electricity and/or renewable biofuels. The limestone-related emissions of carbon dioxide that still exist are managed through CCS and CCU, for example for methanol or algae production. Public and private sector initiatives have jointly enabled technology leaps through beneficial cost profiles and a reduction of risk for individual companies. New pricing models have been introduced.

6. Road Map 2045 – journey towards a fossil-free industry

For *machinery operation, internal transportation and refining processes* and based on splitting the period into three parts, 2018–2025 (short-term), 2025–2035 (medium-term) and 2035–2045 (long-term), conceivable development paths to achieve a fossil-free mining and minerals industry have been staked out. Figures 6 and 8 summarise and provide an overview of important milestones in the efforts for a fossil-free industry. Important investments and research and development (R&D) initiatives that are needed over the three time periods are also indicated.

Internal transportation	2018-2025	2025-2035	2035-2045
Teknikläge	• *Additional* 10-50% electrification of machinery and vehicles compared to fossil-fuel powered today • Biofuel is used according to the reduction requirement	• 50-95% more electrification compared to today • Remaining portion fossil-free with biofuels – where electric-powered is not possible • New mines fully electrified	• 100 % fossilfritt • Genomgående elektrifiering, resterande del fossilfri med biobränsle och/eller vätgas • Mycket hög digitaliserings- och automationsgrad
Investments during the period	• Planned investments • Investments in the fuel management system	• Extensive phasing out of older technology/equipment in connection with reinvestment • Both battery technology and hydrogen gas are used in vehicle technology	• Phasing out of the last diesel trucks (a few exceptions) • New investments for new main level Kiruna 2035
Technology development for the following period	• R&D in battery technology-cold climate, increased capacity, vehicle adaptation, etc.) • New truck-trolley solutions • R&D in hydrogen gas and advanced battery solutions • Increased digitalisation	• Commercialisation of battery technology and smart charging • Further developed digitalisation and automation	
Critical requirements (policies, infrastructure, etc.)	• Strategic allocation of biomass • Access to and price structure for biofuels • Taxes and control amechanisms	• Stable and competitive electricity • Battery technology • Access to and price structure for biofuels	• Stable and competitive electricity • Battery technology • Other climate-neutral energy sources

Figure 6. The road to a fossil-free mining and minerals industry in 2045 with respect to internal transportation – summary of important milestones, investments and research and development (R&D) initiatives needed, divided between the three periods. The table summarises the results from discussions at a workshop in March 2018 which was part of the road map preparation process. Deeper analysis was conducted in 2018 and goals and targets may be revised in the course of the process moving forward.

Electricity and electrification may be the dominant solutions for *internal transportation*. The transition to electric power is mainly being driven by technology development and is primarily taking place through constant phasing out and new investment. It is expected that some of the industry's operations will be fossil-free by 2035, helped by a transition to biofuels in areas where electricity cannot be used.

Other machinery operation	2018–2025	2025–2035	2035–2045
Technology status	• Lifts, ventilation, enriching and crushing - already electric-powered • Heating, excavators, lifting tables and cranes – partially diesel but the shift has begun	• 50–95% more electrification compared to today • Remaining portion fossil-free with biofuels – where electric-powered is not possible • New mines fully electrified	• 100% fossil free • Very high degree of digitalisation and automation
Investments during the period	• Planned investments • Investments in fuel management systems	• Extensive phasing out of older technology/equipment in connection with reinvestment	• Ongoing investment cyclesr • New investments for new main level Kiruna 2035
Technology development for following period	• R&D development in battery technology (increased capacity, vehicle adaptation, cold climate, etc.) • R&D in advanced battery solutions • Increased digitalisation	• Commercialisation of battery technology and smart charging • Further developed digitalisation and automation	
Critical requirements (policies, infrastructure, etc.)	• Safety proven (battery fire risk) • Strategic allocation of biomass • Access to and price structure for biofuels • Taxes and control mechanisms	• Stable and competitive electricity • Battery technology • Safety proven (battery fire risk) • Updating of regulations for use of batteries under ground • Access to and price structure for biofuels	• Stable and competitive electricity • Battery technology • Safety proven (e.g. battery fire risk) • Payment for grid-related services (DSM)

Figure 7. The road to a fossil-free mining and minerals industry in 2045 with respect to machinery operation – summary of important milestones, investments and research and development (R&D) initiatives needed, divided between the three periods. The table summarises the results from discussions at a workshop in March 2018 which was part of the road map preparation process. The analysis delved deeper in 2018 and goals and targets may be revised in the course of the process moving forward.

With respect to *machinery operation*, electrification may also be the dominant solution. A lot has already been electrified and phasing out is ongoing. It is also expected that some of the industry's operations will be fossil-free by 2035, helped by a transition to biofuels in areas where electricity cannot be used.

Other machinery operation	2018–2025	2025–2035	2035–2045
Technology status	• Introduction of new fossil-free biofuels for heating and various processes • Flexible heating with bio-coal and bio-oil	• Continued mixing of biofuel • Continued R&D in electrical heating supply	• Direct reduction in commercial operations
Investments during the period	• Investment in biofuel management system	• New, more efficient pellet plants (including electric-powered)	• Transition to electric-powered/climate-neutral heat carriers for pellet plants • CCS/CCU infrastructure established
Technology development for following period	• R&D alternative heating technology (electricity, microwaves, plasma burner, etc.) • R&D HYBRIT • Preliminary study CemZero • R&D CCS and CCU	• Implementation of CCS strategy including plan to deal with industrial emissions • HYBRIT continues • Continued R&D for fossil-free metal production	• R&D system integration
Critical requirements (policies, infrastructure, etc.)	• Programme to study process for fossil-free smelting plants • Efficient and fair permit processes • Define a Swedish CCS strategy • Relevant NO requirements	• Implementation of a CCS strategy including a plan to deal with industrial emissions • Global rules – competitiveness • Prioritisation of waste heat from industry over biomass for CHP • Supply of biomass for industry	• Stable and competitive electricity • CCS accepted, amendment to London Convention • Rebinding in cement accepted in carbon balance sheet

Figure 8. The road to a fossil-free mining and minerals industry in 2045 with respect to refining processes – summary of important milestones, investments and research and development (R&D) initiatives needed, divided between the three periods. The table summarises the results from discussions at a workshop in March 2018 which was part of the road map preparation process. The analysis delved deeper in 2018 and goals and targets may be revised in the course of the process moving forward.

The *refining processes*, on the other hand, require more research and development. Development of several existing technologies will be needed, as well as technology shifts. Biofuel can replace part of today's fossil fuel in the refining processes, but development is needed of both fuel properties and the fuel supply. Electric-powered heating technologies can eventually be used, although they are not yet mature. Research and development are also needed to identify process and system solutions for fossil-free production of other metals. Managing the process emissions from lime and cement production requires strategies, development and commercialisation of new technology for carbon capture and storage (CCS) and carbon capture and utilisation (CCU) in other industrial process.

7. Critical opportunities, obstacles and barriers

The mining and minerals industry is optimistic that the transition will be successful and is prepared to invest. Necessary development will, however, be time-consuming and will require substantial capital. The key to the conversion is a long-term approach in political decisions and priorities so that the industry will be able to maintain and/or increase its global competitiveness. To succeed with the transition, critical conditions need to be met; for example, a number of obstacles need to be removed and barriers overcome so that the road map can become a reality. The industry's interpretation of these is summarised below.

Efficient and fair permit processes so that new and necessary, climate-efficient investments can be made

Competitiveness and investment capacity are impacted by the process of obtaining the permits required to run and develop mining and mineral projects. Mining and mine-

ral operations involve building costly operations that need to be tailored to each individual project. Geology and other natural conditions vary from place to place, and there are no easy solutions that fit across the board. Since operations also develop and change over time, recurring reassessment is usually needed. This is the case both when new technology is introduced, when production is increased or where operational changes are made.

The mining industry in Sweden is regulated under the Minerals Act (exploration permit and refining concession) and the Environmental Code (environmental permits). The Environmental Code applies alongside the Minerals Act. Before a mine opens in Sweden there is a thorough assessment of compliance with both the Act and the Code. At this time there is a trend whereby the permit review process is taking longer and longer and consuming more and more of the applicant companies' resources. For industrial minerals (limestone) the above-mentioned problems are the same with respect to the Environmental Code. They are not, however, subject to the Minerals Act (mining concession). The Bunge permit case on the island of Gotland is perhaps the most extreme example of the drawn-out process. The permit review process there has been ongoing for 10 years and is not yet concluded (industrial minerals, review under the Minerals Act).

When production capacity is to be increased or new technology installed, or when a new mine will be opened, there is an opportunity to invest in new, greener and more climate-efficient systems. New systems could, for example, contain more automated and electrified processes, enabling an emissions reduction, higher efficiency, energy savings etc. Difficulties obtaining permits for operational changes (or permits for new operations) have been an obstacle for new investment and have therefore clearly slowed down the process. This is affecting the conversion to new, fossil-free technology. Over the past decade no new mines with permits pending under the Minerals Act and the Environmental Code have been established outside areas where there is currently mining activity.

It is very hard to pursue long-term and innovative activities under such circumstances or to take long-term investment decisions when the future of the venture is uncertain. The system therefore needs to be overhauled to ensure efficient and fair permit processes so that new and necessary, climate-efficient investments can be made.

Comprehensive approach in political decisions to avoid control mechanisms that sub-optimise competitiveness and hinder fossil-free progress

The mining and minerals industry is characterised by very large investments with a long time horizon. Some measures can be implemented quickly and easily at limited cost, but to achieve the conversion that will be necessary in the industry, a sufficient and reasonable amount of time must be allowed. This is important to enable real changes to be made involving long-term and robust measures. Maintaining or improving competitiveness is imperative if companies in the mining and minerals industry are to be able to make investments for adaptation or in new processes necessary for conversion.

The mining and mineral companies are price-takers in an international market, which means that the price of production is set on international stock exchanges and costs (investment and operations costs) cannot be passed on to the customers. Investments in fossil-free technology, over and above what is planned for within regular investment cycles, requires profitability and strong balance sheets. Investment capacity is impacted by the industry's profitability. Thus that taxes and control mechanisms should take into account the importance of having the necessary conditions in place for the industry to remain competitive globally. It is important for there to be no "short-term obstacles" or a risk of sub-optimisation preventing long-term investments. Otherwise there will be a significant risk that companies operating in multiple countries will choose to invest elsewhere and not in Sweden.

Apart from investment capacity, there is also the issue of overall costs; the technologies to be used must eventually be competitive in a life-cycle perspective. Since the mining and minerals industry is exposed to international competition, it is generally only

The mining and minerals industry is characterised by very large investments with a long time horizon.

possible to make large investments when the risk of extra expense is low. Technology development in other sectors as well as policy issues often influence which technologies are available to the mining and minerals industry.

Recycling metals through extraction from scrap electronics and lead batteries is important in the process of resetting towards a circular economy. Scrap electronics are dismantled and plastic and other materials are separated to the greatest extent possible. However, the metal and plastic in the remaining components (e.g. in circuit boards) are closely interwoven. Therefore, in order to access valuable metals, some burning of fossil plastics is needed in the metal recycling process. There is no alternative to this today, and when scrap electronics are instead exported to other countries, the way they are processed often has significant social and environmental impacts. It is therefore important for Swedish control mechanisms to enable scrap electronics to be salvaged in Sweden. Over time it would also be beneficial to have improved product design criteria and better dismantling processes.

Last but not least, it is very important for there to be a cohesive approach to all energy and climate policies, long-term national objectives and issues such as access to biofuels and green transportation – with a common emphasis on reaching zero emissions and maintaining Sweden's competitiveness. Here, the companies need long-term and known conditions in order to make investments and pursue development.

The climate is a challenge for the global community. All countries must do their part to fulfil the climate agreement established in Paris in December 2015. It is therefore important for similar control mechanisms to be put in place in other important economies. Swedish climate policies need to be designed for retained competitiveness without increasing greenhouse gases outside Sweden. Regular external situation analysis is needed for the process of establishing Swedish future climate policies.

Investment in research and development for fossil-free production processes and CCS, including testing facilities and upscaling

We are at a stage where technological advances and infrastructure investment are essential to reduce emissions further – and an industry exposed to competition cannot do it all on its own. Some technologies are in place, while others need to be tested, developed and commercialised. Some reconstruction and new construction of core processes will be needed. The industry can pay for part of it but will need government support for research, commercialisation and to share the risk. The globally unique HYBRIT and CemZero projects are substantial and important examples of a focus on fossil-free and climate-smart production by companies in the industry. Cooperation between actors in society, such as policy-makers, public agencies, industry, to produce strategies and projects is crucial. Collaboration with the academic sphere is also essential.

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The technology leaps required in multiple areas are costly and cannot be financed by individual companies. Economic and innovation policies must support the work being done by companies to achieve the desired development by finding new solutions and creating technical innovations. Research funding for universities, and grants for various research programmes, e.g. through Vinnova, are essential for success. Government funding and broad-based cooperation between research and innovation actors in society are essential throughout the innovation cycle – from basic research, pilot scale projects and testbeds, to full-scale implementation. Investments in development of, for example, new industrial processes where the public and private sector work together, could result in large and lasting climate gains. One good example is an initiative launched to reduce emissions for the basic materials industry called Industriklivet.

Sweden has a mining and minerals industry that is at the forefront from an energy, climate and environmental perspective and is therefore in a strong position to drive development further. Investment in the Swedish mining and minerals industry and opportunities for text beds and pilot programmes etc. that already exist should spread positive climate effects to other countries through the export of both know-how and products.

A significant percentage of the industry's climate emissions come from raw material

refining processes. One big challenge is process emissions, i.e. the emissions that occur chemically in the conversion of products (such as when limestone is burned to produce lime, emitting carbon dioxide). A large proportion of the emissions from lime production are process-related emissions, averaging around 70 percent. The amount of process-related emissions from cement production is around 60 percent. Process emissions cannot be reduced by switching the fuel used; instead, in order to achieve significant emissions reductions from some industrial processes, it will probably be necessary to use carbon capture and storage (CCS) and carbon capture and utilisation (CCU). This will, however, require commercially viable carbon capture solutions to be in place, and infrastructure and storage or recycling options to be commercially available.

Today there are large technical, economic, infrastructural and political barriers that need to be overcome before an expansion of CCS is possible. At this time the existing infrastructure for transporting and storing carbon dioxide in Sweden is lacking and substantial investment and measures will be needed to meet the future need. The cost of carbon capture, transportation and storage needs to be significantly reduced from today's levels. Commercialisation of CCS requires infrastructure, cluster cooperation, permits and business models. Also CCS is expected to be able to be used mainly at large facilities as CCS requires a certain scale. Solutions also need to be available for smaller facilities at a reasonable cost.

Facilitation of access to fossil-free electricity with a low system cost and high reliability

Many of the industry's conversion strategies are based on electrification of machinery and processes. A stable supply of electricity is essential. Sweden should have an electricity system that increases Swedish basic industry's global competitiveness through low system costs, high reliability, being fossil-free and having a limited environmental impact. Electricity usage is also expected to rise with increased electrification, automation and the replacement of fossil fuels. An increase in Swedish mining production, which also increases domestic energy consumption, reduces global emissions, which is a desirable outcome.

Competitive electricity prices are essential in order for these investments to be competitive. This should be taken into account in decisions on price-increasing grid connections to the continent. The indirect price increase on electricity from trading in emission allowances will also impact the competitiveness of electricity. Compensation for these indirect price increases at the national level would be desirable (as is the case in Finland, Norway, Germany, UK, the Netherlands and France).

Access to biofuels at a competitive price and strategic allocation of biomass

The amount of biofuels needed for the conversion is substantial. The fuels are needed for internal transportation, heating and ventilation as well as certain refining processes. Most industries will use biofuels in the fossil-free conversion. Competition for biofuels will therefore increase and there is a risk that the supply will not meet the demand. It is possible that there may quite simply not be a sufficient supply of biofuels for a conversion of the Swedish industry to take place. The supply of HVA – which today is the main alternative to fossil diesel – is uncertain for both the short and long term, especially HVO from sustainable raw materials which is expected to be able to significantly reduce greenhouse gas emissions.[16] There is also concern about the price structure resulting in biofuel use reducing the profitability of the companies. Biofuels today are more expensive than fossil alternatives and the increased cost that using these fuels will cause may not be able to be transferred by the mining and minerals industry to its end customers. There is also uncertainty about functionality and guarantees for using biofuels in vehicles and work machinery, especially in mines, given that the majority of these are located in colder climates.

Many of the industry's conversion strategies are based on electrification of machinery and processes. A stable supply of electricity is essential.

16 Sweco, 2017. Konsekvenser av Sveriges klimatpolitik i transportsektorn. https://www.svensktnaringsliv.se/migration_catalog/Rapporter_och_opinionsmaterial/Rapporter/konsekvenser-av-sveriges-klimatpolitik-i-transportsektorn_694005.html/BINARY/Konsekvenser%20av%20Sveriges%20klimatpolitik%20i%20transportsektorn.pdf

In addition, the diesel reduction requirement (and gasoline) may create unwanted negative lock-in effects. Where operations cannot be transitioned to 100 percent electrification all at once, or where the options are limited due to site-specific conditions, investments still need to be made in biofuels to meet the reduction requirement. For the mining and minerals industry this often means investments in refuelling infrastructure and fuel management. This may lead companies to decide to focus their investments on biofuel alone, despite the fact that electrification is the preferred solution over time. This could result in a sub-optimised situation, especially as biofuels may be more important in, for example, other transportation contexts where routes are longer and more irregular.

A stable supply of biofuels with the right properties and at competitive prices is the key to implementing the conversion in the right way. The application and design of future control mechanisms like the reduction requirement must take this into account. Strategic prioritisation and allocation of biofuels in society are therefore needed. This must be reflected in political goals and control mechanisms at the same time as politicians need to take a more technology-neutral stance on how to reduce greenhouse gases.

Cooperation and continual dialogue between various actors in society is crucial if Sweden is to become a fully fossil-free society. In other words, the public sector and other actors need to work together to make the right decisions, to carry the cost of the conversion and to ensure development, and thereby create the right conditions to achieve global and national climate goals.

Important contributions from policy-makers

The most important ways identified by the industry in which policy-makers can make a difference are:

- Efficient and fair permit processes so that new and necessary, climate-efficient investments can be made.
- Comprehensive approach in political decisions to, for example, avoid control mechanisms that sub-optimise competitiveness and hinder fossil-free progress.
- Investment in research and development for fossil-free production processes and CCS, including testing facilities and upscaling.
- Facilitation of access to fossil-free electricity with low system costs and high reliability.
- Access to biofuels at a competitive price and strategic allocation of biomass.

NOTES

Svemin is an industry association for mines and producers of minerals and metals in Sweden. Svemin represents around 40 companies with just over 13,000 employees working in production, prospecting and engineering. The member companies include mining companies, prospecting companies, limestone and cement companies and machinery and contracting companies. Member activities take place throughout the country. The mines are located in Northern Sweden and Bergslagen.

SveMin

www.svemin.se