HYBRIT

FOSSIL-FREE STEEL

A joint venture between SSAB, LKAB and Vattenfall

Summary of findings from HYBRIT Pre-Feasibility Study 2016–2017

This work was funded by the Swedish Energy Agency, SSAB, LKAB, and Vattenfall

PHOTO LKAB

HYBRIT - TOWARDS FOSSIL-FREE STEEL

HYBRIT – short for Hydrogen Breakthrough Ironmaking Technology – is a joint venture between SSAB, LKAB and Vattenfall, aiming to replace coal with hydrogen in the steelmaking process. HYBRIT is a groundbreaking effort to reduce CO_2 emissions and de-carbonise the steel industry.

GROWING GLOBAL DEMAND FOR STEEL

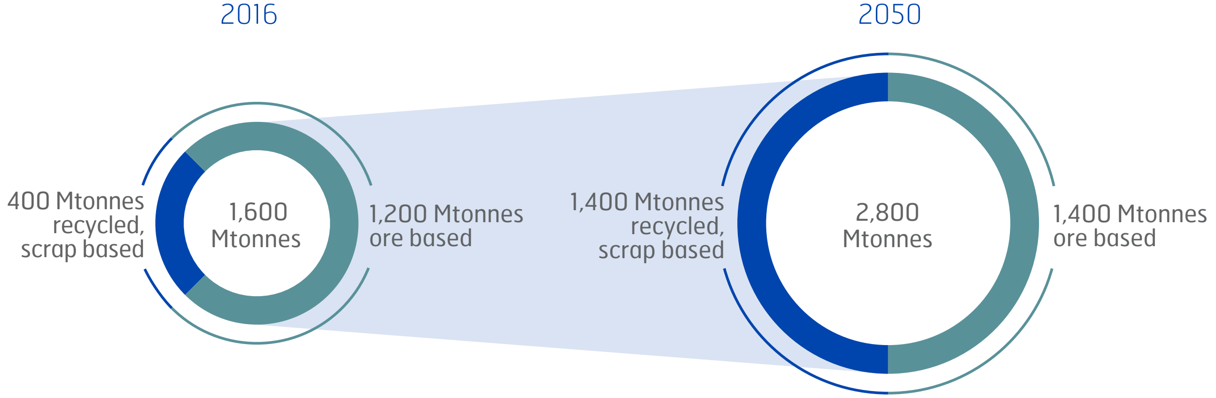
Steel is an important enabler for building the modern society, including industry, innovation and infrastructure. Steel helps to fight poverty and raise living standards throughout the world.

The steel industry is one of the highest carbon dioxide emitting industries, accounting for up to 7% of global, and 10% of Swedish CO_2 emissions. Sweden has set a national target to reach zero net emissions of carbon dioxide by the year 2045, defining the future pathway for the country's steel industry. Sweden offers favourable conditions for HYBRIT to contribute to these national targets, such as high-quality niche production of iron-ore pellets, a specialised and innovative steel industry, and an abundant supply of fossil-free electricity.

Steel is one of the world's most recycled materials. Once it has been produced, the material can be used repeatedly via the scrap-based production route. Even though steelmaking from recycled scrap has been estimated to increase drastically, the overall demand for steel in the next few decades can only be met by utilising ore-based virgin iron as well.

Although the HYBRIT route of fossil-free industrial production will face challenges, it offers a great opportunity to reach new global markets for green technology and products. As a demonstration of science and innovation, HYBRIT has the potential to sustain Europe's leading position in fighting climate change while strengthening competitiveness.

Steel demand – today and forecast 2050



The material properties and metallurgy of steel make it one of the world's most versatile and recyclable materials.

DECOUPLING OF CARBON DIOXIDE AND ENERGY

The HYBRIT concept enables the decoupling of energy carriers and reduction agents generating carbon dioxide.

The ore-based steelmaking value chain starts at the iron ore mine. After mining, the iron ore is processed, and a product rich in iron oxides is produced in the form of pellets, or fines. At the steelmaking site, iron ore is converted to metallic iron by reduction of the iron ore pellets with coke in a blast furnace. The iron oxide and carbon then react to form CO and CO_2 gases, as well as metallic iron. Now in liquid form, the iron is further processed before a semi-finished steel product is cast.

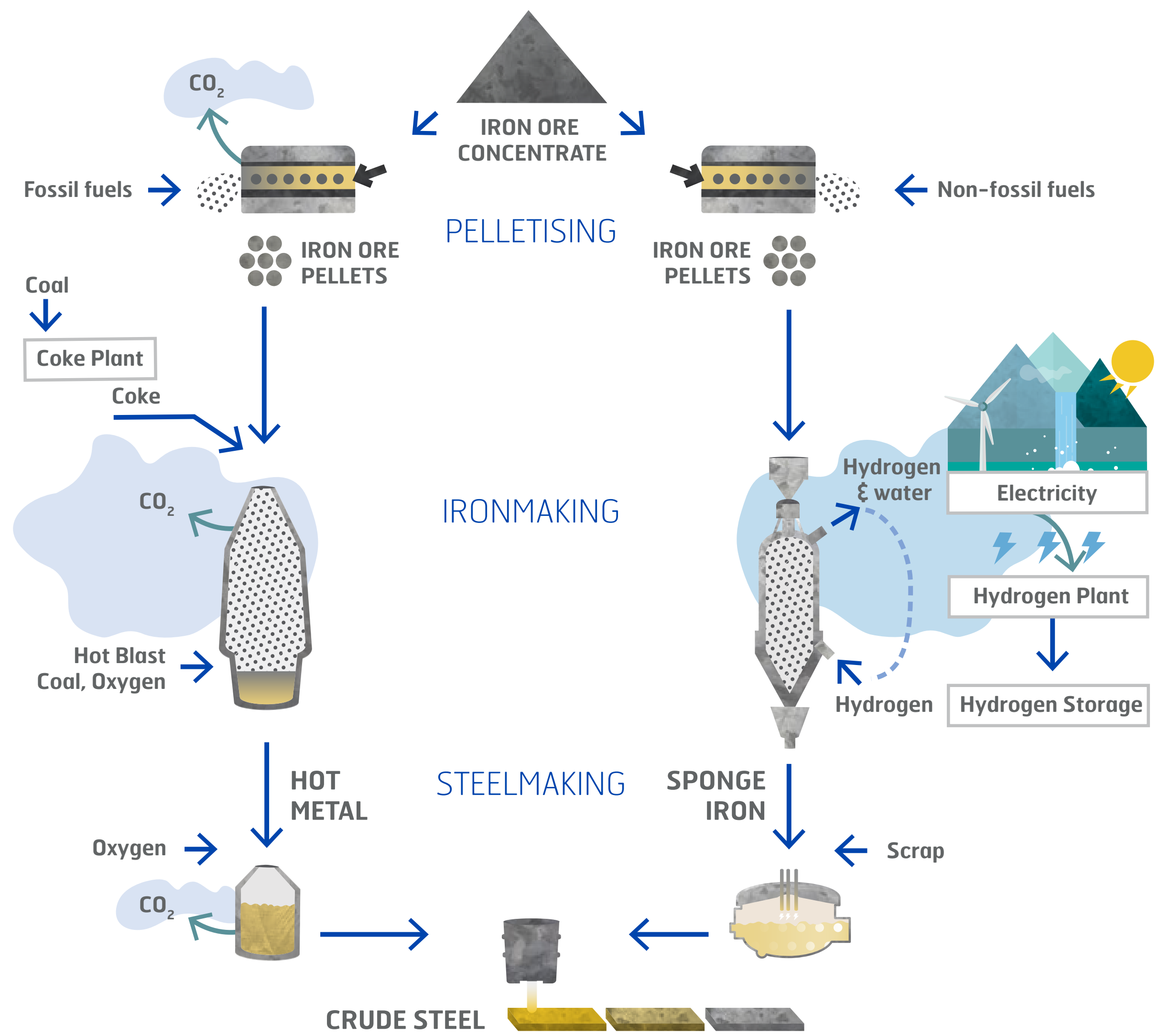
An alternative to the dominant blast furnace ironmaking route is to use the so-called direct reduction process where natural gas replaces coke as the main reductant, and the main product is solid sponge iron. The iron then needs to be melted using an electric arc furnace, before steel is produced. Currently, this gas-based direct reduction process is not used in Sweden, but is an option in other parts of the world where natural gas is in abundance.

WATER INSTEAD OF CARBON DIOXIDE

The reduction reactions in ironmaking represent around 85 to 90 per cent of the total carbon dioxide emissions in the ore-based steelmaking value chain. In addition, the energy-containing gas from coke ovens and blast furnaces has an important role as the main energy source for heating furnaces and materials. Fossil-free steel production will eliminate the formation of CO_2, by using fossil-free reductants and energy sources.

In the case of HYBRIT, iron metal is produced by using hydrogen gas as the main reductant. The production route is similar to existing direct reduction processes, except for the carbon dioxide emissions: hydrogen reacts with iron oxides to form water instead of carbon dioxide. Hydrogen gas (H_2) is produced by electrolysis of water using fossil-free electricity, which is already the standard in Sweden.

BLAST FURNACE ROUTE | HYBRIT ROUTE



FOCUS ON FUTURE DEVELOPMENT

The HYBRIT prefeasibility study provided encouraging results – no new showstoppers were discovered.

PROMISING TECHNOLOGICAL POTENTIAL

The prefeasibility study results underline that no major, previously unknown technical obstacles have been identified. Nevertheless, considerable future development efforts will be required to realise and verify the concept, and to handle risks. These include fundamental research projects using models and laboratory scale experiments, as well as trials in pilot and demonstration plants.

PRODUCTION COSTS SEEM VIABLE

Considering current cost levels, an iron- and steelmaking value chain based on the HYBRIT concept would result in a 20 to 30 per cent increase in the cost of producing crude steel. The cost structures of fossil and fossil-free value chains are strongly dependent on the prices of coking coal, electricity and emission rights. An expected future shift in costs and market demands makes the fossil-free HYBRIT concept an attractive alternative.

HYDROGEN AS WIND AND SOLAR BUFFER

Large-scale hydrogen production and storage will allow for flexibility in power consumption on a large scale, which will favour the implementation of intermittent renewable energy sources for electricity production.

PROMOTION OF HYDROGEN TECHNOLOGIES

Large-scale hydrogen production will boost the transition to other hydrogen-based technologies and spur innovation and business spin-offs associated to the hydrogen society.

SOCIETAL SUPPORT NEEDED

Electrical infrastructure expansions and regional transformation support are fundamental requirements for the concept. Competence and capacity building will support the future value chain production systems and business models. A viable business case may be dependent on carbon dioxide instruments, as well as development of niche markets for fossil-free iron and steel.

Support from society will be required to make the transition manageable

TAKING THE GREEN ROUTE

To avoid future emissions, the solutions under development have to be technically and economically viable.

When calculating initial emissions of the current dominant production process, both direct and indirect emissions were included. In Sweden, the carbon dioxide emissions using current technology are 1.6–1.7 tonnes of CO_2 per tonne of crude steel, compared to the estimated 2.0–2.1 tonnes of CO_2 for a typical integrated steel plant in Western Europe. The result can be explained by differences in the electricity mix, with more renewable sources available in Sweden. Another factor is the high level of energy efficiency in the Swedish industry, where LKAB and SSAB are leading operators in terms of energy and CO_2 efficiency.

ASSESSMENT OF CAPITAL AND OPERATING EXPENSES

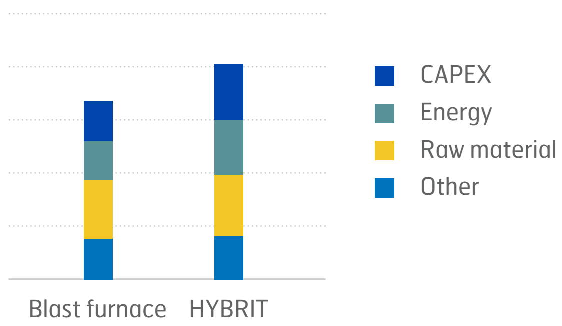
Capital costs have been estimated for the construction of respective production systems in greenfield conditions. This is, however, a generalisation considering that there is a functioning production system in place that needs to be restructured. Replacing major parts of the existing infrastructure in steelmaking will be very expensive. Therefore, careful planning is important, so that the transition is carried out when previous investments have reached the end of their life cycle.

The estimated total cost per tonne of crude steel has been calculated based on current commodity and energy prices. The indication is that the production cost for steel via the HYBRIT route is approximately 20 to 30 per cent higher than for the reference case. In the steel industry, commodity and energy prices may fluctuate considerably over time, and there are several factors indicating that the relative cost level can change during the HYBRIT planning horizon.

The main factors affecting HYBRIT in the long run are mainly price developments for coking coal, electricity and emission allowances. If coking coal prices increase, it will benefit the HYBRIT business case, while increasing electricity prices will weaken HYBRIT. Also, future developments of the emission trading system EU ETS will have an impact.

Although a complete replacement of carbon by renewable energy will result in an increase in material costs, the impact on the end-user product is neglible. Predictions of future costs are highly uncertain, but anticipated shifts in prices and market demands make the fossil-free HYBRIT concept a commercially attractive option.

Cost comparison



Estimated crude steel production costs at greenfield conditions (HYBRIT prefeasability study).

Transition costs very high.

HYBRIT production costs viable.

Additional cost for end-user limited.

REFERENCE CASE

Even though the existing LKAB-SSAB production system is one of the most efficient of its kind worldwide, it emits around 6 million tonnes of carbon dioxide per year in Sweden.

IRON ORE

Typically, the fine iron ore concentrate contains more than 71 per cent iron.

PELLETISING ❶

In the pelletising plant, the fine iron ore concentrate is dewatered, and a binding agent is added before the concentrate is rolled into 10-millimetre pellets. The pellets are dried, preheated, sintered, and cooled down before storage and transportation to steel plants. The magnetite ores in northern Sweden are especially suitable for such processing. During the process, the magnetite is oxidised into hematite. This reaction releases heat, which replaces about two thirds of the fossil fuel needed when pellets are produced from hematite concentrate.

COKE PRODUCTION ❷

Coke is a stable fuel and reducing agent with a high carbon content, made from coal. Parts of the volatile matter in coal are used as energy for the high temperature baking process in coke production.

BLAST FURNACE ❸

The iron ore and coke is added to a process designed to release oxygen from the iron ore according to the simplified reaction: iron ore + carbon => iron + carbon dioxide. This takes place in a shaft furnace where the solids are charged to the top of the furnace, and preheated air is injected in the lower parts to enable an efficient heat transfer. The result is a molten hot metal consisting of iron, with 5% of dissolved carbon.

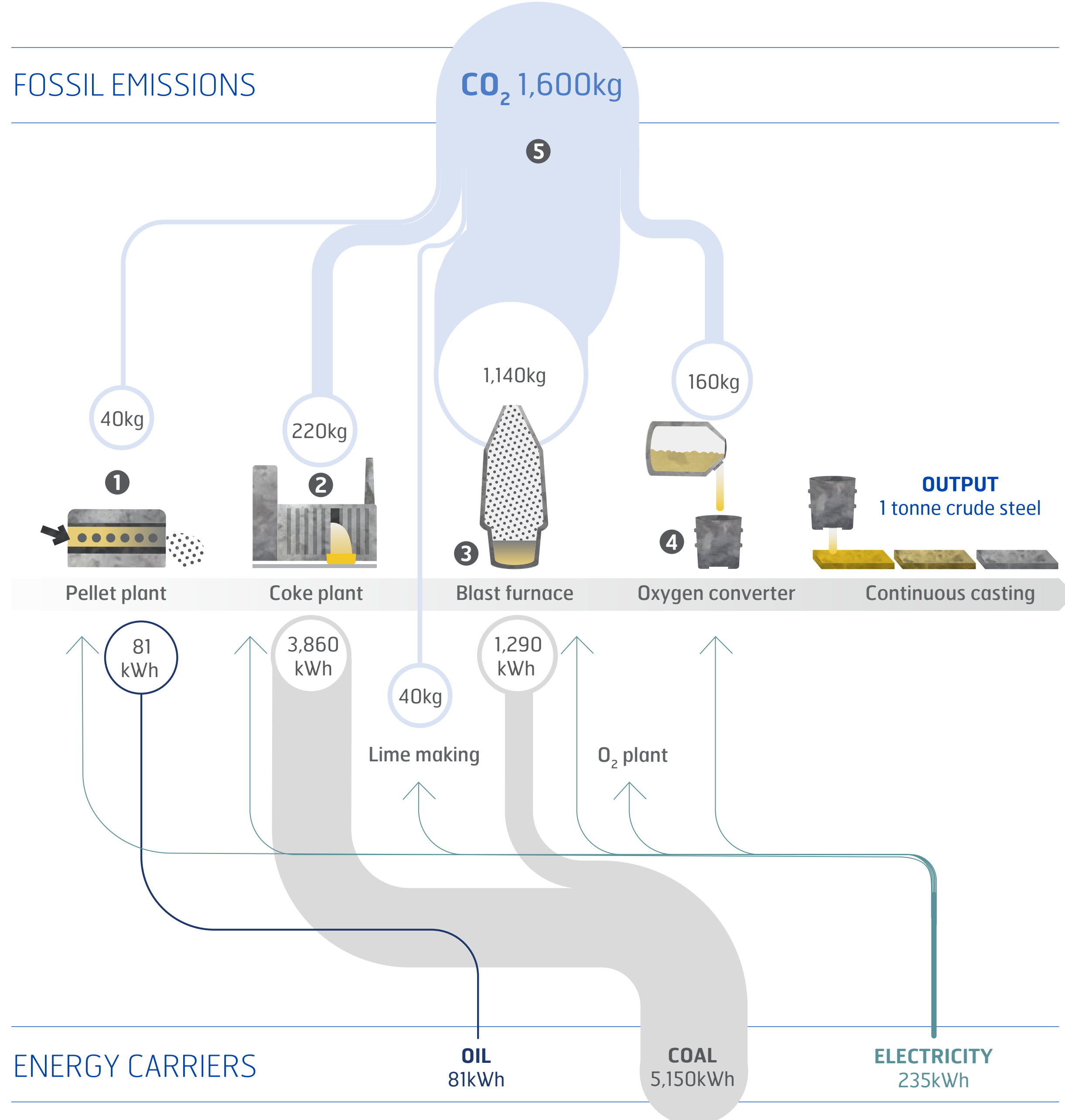
OXYGEN CONVERTER ❹

The hot metal is treated with oxygen gas to lower the carbon content and form molten steel. The reaction releases heat, which is utilised to melt an additional 10-20% of steel scrap, before the liquid steel is tapped into a ladle, where the final chemical composition and the temperature of the steel is adjusted. After this, the steel is cast into crude steel slabs in a continuous caster.

CO_2 ❺

Carbon dioxide originates from the blast furnace, coke making, decarburisation of hot metal in the converter process, and fossil fuels used in the pelletising process.

SWEDISH REFERENCE



Principal system description. Numbers do not reflect a specific production site or time period. All numbers per tonne of crude steel.

HYBRIT IMPLEMENTED

The HYBRIT system uses hydrogen – produced using fossil-free electricity instead of fossil coal – and releases water instead of carbon dioxide. If realised on an industrial scale, the technology could make Sweden the world's first country to produce fossil-free ore-based steel.

PELLETISING ❶
The fossil fuel in ore processing will be eliminated with an increased level of energy efficiency and by switching to fossil-free sources of energy.

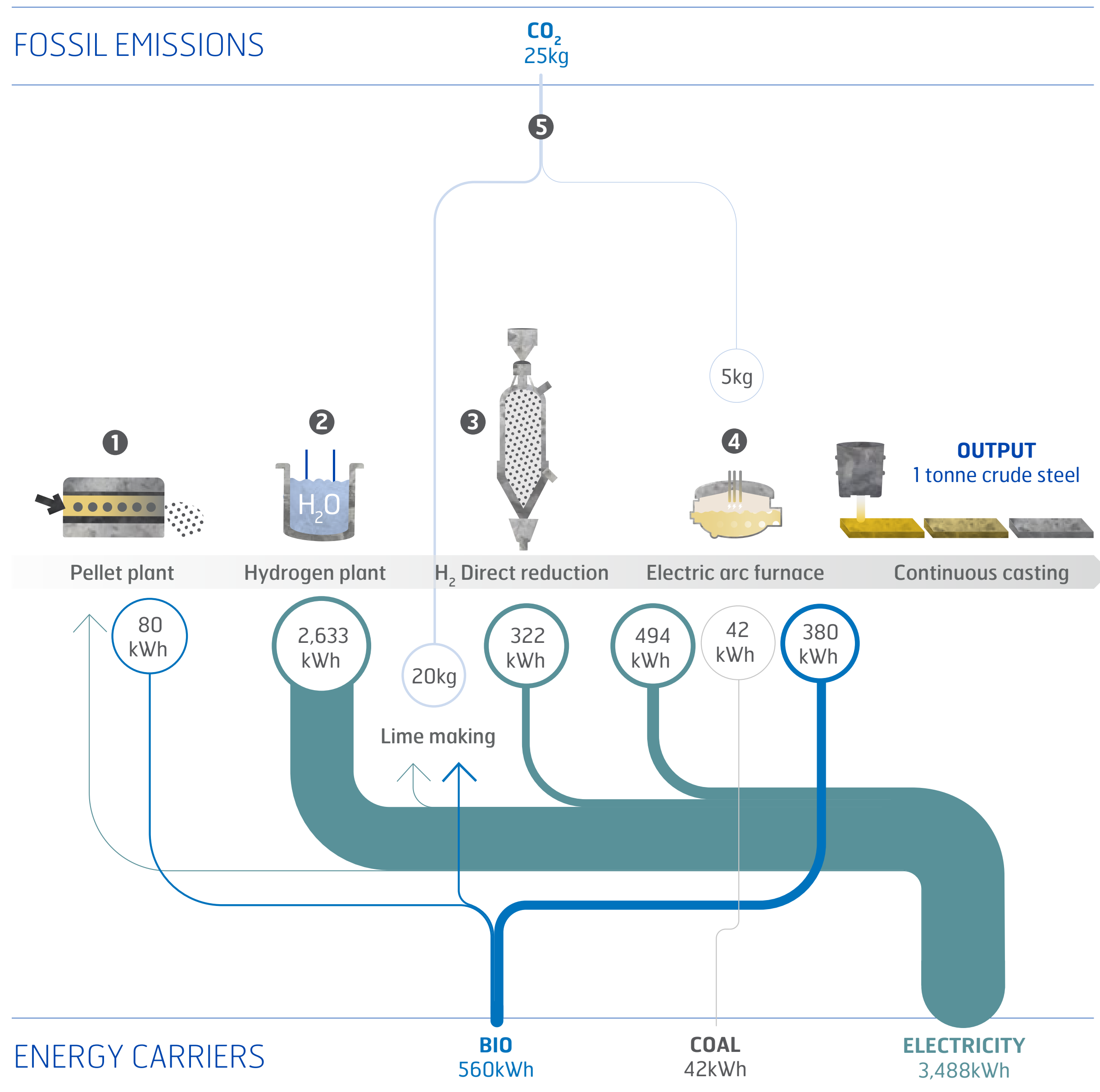
HYDROGEN PLANT ❷
Hydrogen production takes place by electrolysis of water into hydrogen gas and oxygen. Renewable electricity is the primary energy source. Electrolysis is a mature technology, and principally, there are no barriers to building a large-scale plant.

DIRECT REDUCTION ❸
The existing direct reduction method needs to be adapted to reduction with hydrogen to eliminate carbon dioxide emissions. The off-gas of the reduction process would be water, according to the simplified reaction: iron ore + hydrogen => iron + water. The result is a solid porous sponge iron, suitable for steelmaking.

ELECTRIC ARC FURNACE ❹
The Electric Arc Furnace (EAF) is used for heating and melting charged materials by means of electric current. The use of EAFs allows steel to be made from up to 100% scrap metal, or as in the HYBRIT concept, from a mix of direct reduced iron and scrap. Similar to the reference process, the liquid steel is tapped into a ladle where the final chemical composition and the temperature of the steel is adjusted, before it is cast into crude steel slabs in the continuous caster.

CO_2 ❺
CO_2 emissions will be reduced dramatically, although minor emissions can still arise because of the use of certain process equipment, and because small amounts of coal must be used in the manufacturing process.

HYBRIT



All numbers per tonne of crude steel.

RENEWABLE ELECTRICITY SUBSTITUTES COAL

Implementing de-carbonised ore-based steel production before the year 2045 will contribute significantly to the target of a fossil-free Sweden.

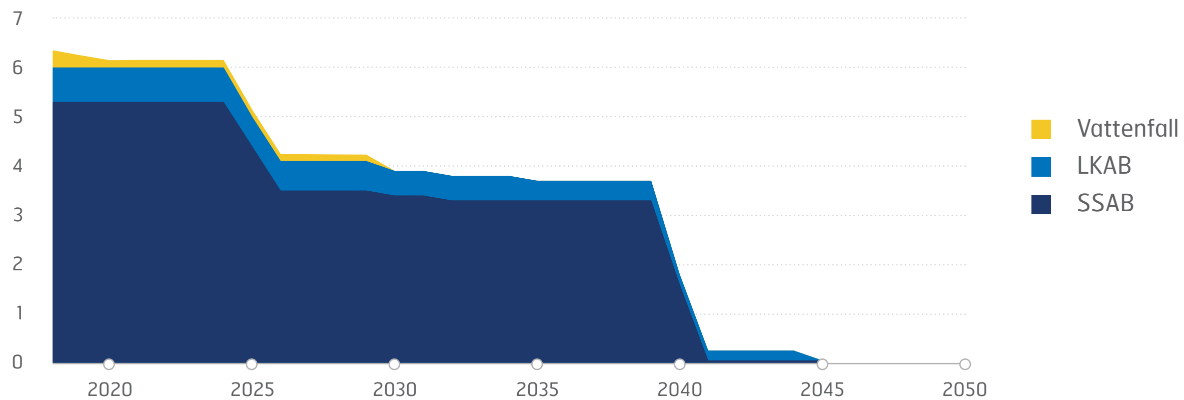
The figure below shows the summation of the carbon dioxide reduction roadmap for emissions in Sweden for SSAB, LKAB and Vattenfall. In the short term, LKAB will achieve a gradual reduction by further energy efficiency measures and fuel substitution. The final elimination of emissions will require technological advances to be implemented by 2045. The SSAB roadmap includes a first transition step to electric melting in 2025 and, if the conditions allow, a second transition step to electric melting before 2040.

The most significant steps with regards to CO_2 reduction are associated with the phasing out of blast furnaces, substituted by hydrogen-based direct reduction plants and electric arc furnaces. The primary iron source in steel plants will then shift from blast furnace iron to hydrogen-based direct reduced iron, using the HYBRIT production principle.

After this development, electricity from renewable sources will be the primary energy carrier and consumption will increase in the order of 15 TWh, primarily to be used for hydrogen electrolysis and steel melting processes.

Contribution to territorial Carbon footprint in Sweden

(Mtonnes/year)



IDENTIFIED MAIN CHALLENGES

In order to obtain a viable fossil-free industry, a massive effort to resolve certain issues remain, with major challenges in various areas.

THE EFFECT OF CARBON-FREE PROCESSING must be clarified. Carbon is arguably the most important element in traditional iron- and steelmaking. Without carbon added in any substantial amount, there is a need to understand mechanisms and define process principles.

HYDROGEN PRODUCTION will be based on existing commercial technology, yet to be proven on a large scale. Controlling scale effects will thus be important for process functionality and economics.

HYDROGEN STORAGE plays an important role in the value chain economics and integration. Technology for large-scale hydrogen storage is still untested.

FOSSIL-FREE FUELS AND TECHNOLOGIES FOR PROCESS HEAT will be required to replace existing fossil heat sources in the production system.

AN OPERATING PRACTICE needs to be established in the new process to function as a stand-alone unit, and as part of a value chain technically and economically optimised on the system level.

THE ELECTRICITY SUPPLY AND TRANSMISSION from renewable sources to the future production sites plays an important role to secure the foreseen increased demand of electricity.

REGIONAL EFFECTS ON SOCIETY will be considerable in the areas where transition will take place, requiring further consideration.

POLITICAL INSTRUMENTS, e.g. emission trading, will affect the industrial transition period and the likelihood of a viable business case.

THE FUTURE BUSINESS CASE for a fossil-free iron and steel product requires further in-depth studies to find the most likely future scenario and related business model.

THE INDUSTRIAL TRANSITION STAGES and associated technological and economic effects represent considerable risks and costs for the companies involved, which need to be resolved.

GOING FORWARD

The HYBRIT initiative roadmap remains intact. The pilot phase will begin in 2018, with initial activities aiming to prepare design and construction in order to have a pilot plant operational in 2020.

Main project phases

2020 · 2025 · 2030 · 2035

2016–2017
PRE-FEASIBILITY STUDY

2018–2024
PILOT PHASE
- 2018–2020 Pilot line design and building phase
- 2021–2024 Pilot line trials

2025–2035
DEMONSTRATION PLANT TRIALS

SSAB
+46 8 45 45 700
INFO@SSAB.COM
WWW.SSAB.COM

LKAB
+46 771 760 000
INFO@LKAB.COM
WWW.LKAB.COM

VATTENFALL
+46 8 739 50 00
WWW.VATTENFALL.COM

HYBRIT DEVELOPMENT AB
CONTACT@HYBRIT.SE
WWW.HYBRITDEVELOPMENT.COM

PHOTO **JOHN TOWNER**