CHAPTER 2E

The Sponge-Iron Battle:
The Challenges for Fossil-Free Steel Initiatives in Norrland and the Way Forward*

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Introduction

The EU and many countries have committed to be climate-neutral by 2050. Combined with the Paris Agreement, this means there is strong pressure to transition to climate-neutral technologies. This pressure also applies to the steel industry, which accounts for around 8% of global CO_2 emissions.[1] The mining, iron, and steel industry worldwide is thus facing a period of sharp demands for transition to reduce emissions while remaining profitable.

The EU's climate targets are stricter than those of the Paris Agreement, putting more pressure on the European iron and steel industry to adapt. The previous free allocation of emission allowances to the iron and steel sector under ETS1 will be phased out by 2034. At the same time, emissions will be reduced by restricting the new issuance of allowances at a faster pace and beginning in 2039, the issuance of allowances will cease altogether. To prevent production from moving outside the EU and to prevent non-EU producers from gaining competitive advantages on the EU market, a border adjustment mechanism that prices the emissions of imported iron and steel products—the Carbon Border Adjustment Mechanism (CBAM)—will be introduced concurrently. This will function as an import tariff (customs duty). The level of the tariff will be determined by the price difference between emission allowances within the EU and the region from which the products are imported.

The part of the value chain from mine to finished steel that currently emits the most carbon dioxide is the production step between iron ore and iron, in which the oxygen is removed from the iron ore. This step has long been carried out in blast furnaces where coal is used both as an energy source and as a means of removing the oxygen from the ore. Approximately 70% of all steel globally is produced in this way. The method currently results in over 1.6 tons of carbon dioxide emissions per ton of steel produced. In addition, other parts of the value chain produce approximately 0.4 tons of such emissions.[2]

An alternative way of removing oxygen from iron ore is by means of sponge iron. This substance consists of between 90 and 95% pure iron. The production process requires high quality iron ore; the iron content must be at least 65% and preferably higher than 67%. Currently, natural gas is used in sponge iron plants. For this reason, most sponge iron plants are located in regions with ready access to cheap natural gas, such as the Middle East, Iran and Russia.[3] The natural gas-based process of removing the oxygen from the ore causes carbon dioxide emissions of about 0.6 tons per ton of steel, which is 60% less

1 Estimates range from 7.2% (Carbon Brief) to 11% (Our World in Data) of total global carbon emissions (https://www.sustainable-ships.org/stories/2022/carbon-footprint-steel).

2 Sommers (2022).

3 Midrex (2023).

than what is produced in blast furnaces.[4] As the need to reduce carbon emissions has become more important, the demand for sponge iron has consequently increased. As a result, the number of production facilities and production have increased significantly, especially in the last five years. However, the share of iron produced via sponge iron is still only about five percent of total iron production, but sponge iron production is expected to continue to grow rapidly to meet rising demand.

The natural gas in sponge iron plants can be replaced by hydrogen, which results in the production of water instead of carbon dioxide as a residual. This technology shift has not been cost-efficient thus far because hydrogen produced by electrolysis requires massive amounts of electricity. In regions with access to cheap natural gas, reducing the oxygen in the iron ore is about five times more expensive when replacing natural gas with hydrogen.[5] However, to capture the potential for zero carbon emissions, experiments are underway around the world, such as capturing the emissions from natural gas or increasing the blending of hydrogen in sponge iron plants as the technologies become more mature and economically viable.

Sweden, through the government-owned company LKAB (Luossavaara-Kiirunavaara Aktiebolag), is the predominant producer of iron ore in the European Union: 85% of the EU's total iron ore production comes from LKAB. Still, from a global perspective, LKAB is still quite small; its world market share is a mere 1%. Together with the government of Finland, LKAB also controls Sweden's largest steel company, SSAB.[6] H2 Green Steel (H2GS),[7] a newcomer in the steel industry, plans to produce five million metric tons of steel annually in their Boden plant by 2030. This is 13% more than the total output of all Swedish steel works in 2022.

In contrast to international efforts, LKAB and H2GS plan instead to make sponge iron production directly fossil-free without transitional fossil solutions using hydrogen instead. The hydrogen will be produced by electrolysis, which requires large amounts of electricity. The cost of electricity is by far the greatest expense in the production of hydrogen-based sponge iron. The companies have therefore chosen to locate their planned production in Norrbotten County on the grounds that the region can offer large amounts of cheap

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4 Sommers (2022).

5 For calculations, see Sundén (2024b).

6 Although LKAB only owns 10.5% of the shares, a large proportion are A shares (which give more voting rights), which means that LKAB has 16% of the votes. The Finnish government is the second-largest shareholder with 6.29% of the capital and 8.04% of the votes (https://www.ssab.com/sv-se/ssab-koncern/investerare/ssab-share/aktieagare, as of March 1, 2024). The two largest owners thus together control only one-sixth of the capital in SSAB, but despite this relatively limited ownership, they de facto control the company.

7 H2GS is a private firm founded by the private equity investor and Altor partner Harald Mix. The company is highly dependent on credit guarantees from national and supranational agencies and organizations. In January 2024, they also received a grant of SEK 3 billion from the European Union's Innovation Fund (Rex, 2024).

fossil-free electricity.[8] The state-owned company Vattenfall is the predominant producer of electricity. In order for LKAB and H2GS to be able to have access to all fossil-free electricity required for the projects, the Swedish government through Vattenfall needs to make the requisite investments in electricity production facilities. Likewise, massive investments in an expansion of the electricity grid must be made by the government agency Svenska kraftnät.[9]

LKAB intends to sell its sponge iron on the world market while H2GS plans to use the sponge iron (in combination with scrap) in its own steel mill to produce steel products. Even though the hydrogen-based sponge iron will be much more expensive to produce than its natural gas-based counterpart, both companies claim that they can reach profitability because they expect to charge a sufficiently high "fossil-free" premium on their products. This premium can be estimated as the difference between what companies producing fossil sponge iron and fossil steel need to pay for their extra emissions within ETS1 in the future compared to LKAB and H2GS. The companies also claim that their customers are already willing to pay this premium in full because the customers aim to be fossil-free as soon as possible.

Thus, the profitability of both LKAB and H2GS as "fossil-free" producers of iron and steel is mainly determined by how cheaply, in a world-wide comparison, they can produce sponge iron—an iron product that has grown strongly in both global demand and production. Their success will therefore depend on who wins the global sponge-iron battle in the iron and steel markets.

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8 Norrbotten County is Sweden's largest and northernmost county, constituting almost one-fourth of Sweden's total land area. The county is sparsely populated, having only 2.4% of Sweden's total population.

9 Svenska kraftnät is the government agency responsible for ensuring that Sweden's transmission system for electricity is safe, environmentally sound and cost-efficient.

Purpose

Against this background, David Sundén has assessed in three reports how well LKAB and H2GS can succeed in global competition. The first report, "From brown to green",[10] assesses the companies' potential for success from a technology and market perspective. The second report, "Profitable or costly?",[11] evaluates the potential for the companies to achieve commercial profitability. The third report, "At any electricity price?",[12] estimates how the companies' high demand for electricity affects the electricity market and electricity prices and how this in turn affects the companies' chances for success.

The purpose of this chapter is to briefly summarize the results and explain why the companies' initiatives must be classified as high-risk projects. We will also try to explain why, despite all the challenges, the projects have come so far in planning and implementation without being questioned. Finally, we also provide a picture of how the initiatives should have been implemented and what should be done to reduce risks in the companies' business.

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[10] Sundén (2023).
[11] Sundén (2024a).
[12] Sundén (2024b).

The challenges in global iron and steel markets

The global iron ore, iron and steel industry has been essentially locked into blast furnace technology for a long time, resulting in continued carbon emissions. This lock-in is due to several factors. First, the blast furnaces in Asia have a very low average age, approximately ten years, which means that they have a remaining average lifespan of 40 years, conservatively estimated.

Second, these blast furnaces are fed with hematite-based iron ore from large mines in Australia and Brazil, mainly owned by the world's four largest mining companies. Hematite ore from these mines currently has limited potential for cost-efficient use in alternative fossil-free manufacturing technologies, either due to low iron content or high levels of impurities. The availability of this type of low-grade ore is significant, and it is well-suited for use in blast furnaces.

Third, this value chain, from lower-grade ore to steel via blast furnaces, has been optimized and is now well proven, industrialized and commercialized. Blast furnace technology is one of the cheapest ways to produce steel. It is therefore a safe and inexpensive way for many developing countries to secure their steel needs for developing their societies and building their infrastructure and cities. The disadvantage is that this technology generates high amounts of carbon dioxide emissions.

Finally, competing technologies such as the production of steel from steel scrap and sponge iron in electric arc furnaces can only contribute to a green transition towards lower carbon emissions to a limited extent. This is due to the limited availability of the scrap steel and high-quality iron ore needed to produce sponge iron.

The process of manufacturing new steel from scrap steel produces low carbon dioxide emissions. Scrap steel can also be used in blast furnaces, reducing the need for coal in the process and consequently emissions as well. As a result, scrap has become a strategically important input for steel companies in their efforts to reduce emissions. To secure access to scrap in their value chains, the largest steel producers have therefore started to acquire scrap companies in the US and Europe. More and more steel scrap is then locked into the value chains of the large companies, reducing the share of tradable steel scrap. However, using scrap steel as an input material to completely decarbonize is not a viable option due to its limited availability. Estimates indicate that scrap could account for 50% of steel production by 2050,[13] which is not enough to reduce emissions to the required extent.

Sponge iron is often portrayed as crucial in the reduction of carbon dioxide emissions, particularly sponge iron produced with hydrogen. The global production of sponge iron has increased significantly over time due to high and rising demand. However, sponge iron should be produced from the highest quality iron ore possible, known as DR pellets. Poorer quality ore—with lower iron content and higher levels of impurities—results in lower efficiency and higher production costs in sponge iron plants.

The demand for sponge iron is thus directly linked to the demand for DR pellets. Sponge iron plants already in the planning stages, mainly in the Middle East, require such large quantities of DR pellets that the supply will not be able to keep up with demand. The reason is that only a few mines have ore of sufficiently high quality; two of these are owned and operated by LKAB. The International Iron and Metallics Association (2023) predicts that after 2030, sponge iron plants will need 30% more high-quality iron ore than will be available from currently operated mines.[14]

Some of this demand can be met by lower-grade ore. For those sponge iron plants that choose this option or are forced into it, production costs will increase due to reduced energy efficiency. There is a high risk that some sponge iron plants will not have access to enough DR pellets to operate at full capacity. In the worst-case scenario, some plants may be forced to close. Against this background, the availability of DR pellets becomes critical for the sponge iron industry; this will limit the ability of the steel industry to decarbonize. At the same time, LKAB's high-quality iron ore becomes a strategically important input in the global iron ore market. The price of LKAB's ore can be expected to rise when the value of this commodity for the global green transition of the steel industry is realized.

In summary, the global steel market is not only locked into blast furnace technology, it also has limited opportunities to switch to the alternative technologies available. At present, the raw materials of steel scrap and high-quality iron ore simply do not meet demand. Our assessment is shared by the largest international mining companies and the major steel companies. They believe that blast furnaces will be used for a long time to come and that the current fossil-free alternatives are not sufficient to reduce emissions to any great extent. Instead, they are investing heavily in attempts to make blast furnace technology fossil free.

Against this market background, the risks of investing in hydrogen-based sponge iron production in Norrbotten County are obvious:

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13 International Energy Agency (2020).
14 See also Kuykendall (2022).

1. *Global market lock-in is driving research and development towards reducing CO_2 emissions from blast furnaces.* The lock-in to steel production dependent on fossil fuels, combined with demands for lower emissions, creates strong pressure for change and willingness to invest in finding technical solutions that reduce emissions from blast furnaces. To put it simply, the owners of blast furnace steel plants are faced with the choice of either losing their investments or making them fossil free. The largest mining and steel producers can therefore be expected to invest extensively in research and development to make this technology fossil free. The "fossil-free" premium that LKAB and H2GS can charge for their products will decrease as blast furnace producers become more proficient at reducing emissions.

2. *Raw materials—steel scrap and DR pellets—are strategically important in the green transition, but they are only available in limited quantities.* Producers who base their steel production on steel scrap and high-grade iron ore face fierce competition for access to these inputs. For H2GS, this means that they have to compete with sponge iron mills in the Middle East, Asia and the US for the high-quality ore. These competitors produce their sponge iron using natural gas and sell it on the world market with little or no extra costs for their carbon emissions. Moreover, the cost of production is significantly lower, giving the natural gas-powered sponge iron plants greater economic margins compared to H2GS when contracting for the supply of DR pellets. In this way, H2GS risks being last in the line of DR pellet buyers and not being able to produce at full capacity or, in the worst case, not at all. Similarly, H2GS risks being at the end of the queue in the competition for high-quality steel scrap. The steel companies producing steel from scrap in electric arc furnaces have a cost advantage as the production cost is not burdened by the production of hydrogen-based sponge iron.

For LKAB, the situation represents a major opportunity to create extra profitability, as its iron ore will be a strategically important input for the green transition. However, investing in refining this raw material with the help of hydrogen involves great risk for the same reasons as noted in the discussion of H2GS. Any producer who manufactures sponge iron using natural gas will have a significant cost advantage over LKAB.

The technical challenges

It is important to understand that the initiatives of LKAB, SSAB and H2GS are based on the same type of technological value chain. The technologies involved in this chain, however, are not groundbreaking—either technically or commercially. The required facilities—electrolysers, sponge iron plants, electric arc furnaces and the facilities that produce finished steel products—are based on established technologies. Thus, the investments cannot have a transformative effect on either the quality of steel or the cost of production; on the contrary, both sponge iron and steel will be significantly more expensive to produce. The value chain requires larger investments than in other technologies and does not in itself provide any competitive advantage, apart from the possibility of producing "fossil-free" steel (in competition with fossil-free steel produced by other technologies). What is new is the feeding of sponge iron factories with hydrogen and the vast scale of hydrogen production using electrolysers required (which, in turn, requires a massive expansion of electricity production and the electricity grid).

In the case of LKAB, the overall technical challenges and risks become clear when one lists the specifics of their overall plans for sponge iron production:

- build hydrogen production based on electrolysis on a scale never achieved, proven to be technically feasible or economically viable,
- build a hydrogen storage facility on a scale that has never been implemented or demonstrated to be technically possible or economically viable, and
- build a sizable number of capital-intensive sponge iron plants powered by hydrogen on a scale that has never been attempted before and with a technology that has not yet been demonstrated to be commercializable or industrializable.

One should also note that LKAB has no experience whatsoever with any of the technologies or in running such extensive projects. The project, technology, and business risks in LKAB's sponge iron venture can therefore only be categorized as very high. A similar situation applies to H2GS, which is a start-up company with owners and management with no experience in the relevant technologies, steel production or iron and steel markets. An additional risk is posed by the fact that pioneering technologies have been shown to work at the pilot stage, and that research and development to reduce carbon dioxide emissions in blast furnaces is increasing and slowly demonstrating their feasibility in reducing emissions.

Examples of pioneering technologies include smelting reduction and smelting electrolysis, which are still at the pilot stage. The advantage here over other processes is that they can produce pure iron more or less directly from any type of iron ore. This chemically pure iron can then be fed to electric arc furnaces for precision production of all types of low- and high-quality steel. In contrast to the traditional process, carbon dioxide emissions can be significantly reduced. Unlike the technologies that rely on sponge iron, these do not require high-quality iron ore. Furthermore, molten electrolysis technology is highly modular, leading to low initial capital requirements and shorter construction times.

The modularity also means that a single successful trial on a limited scale is sufficient to prove its economic potential. The low investment capital requirements mean that the technology can then be quickly and easily commercialized worldwide. Breakthrough technologies, such as smelting electrolysis, have the potential to fundamentally change steelmaking. If such a method proves to be commercially viable, it could attract significant investment within a short time and in many locations around the world. Such developments would fundamentally change value chains and could make some technologies unprofitable.

The pressure to make blast furnace technology fossil-free has intensified and will intensify over time. There are many possibilities, but it has not yet been possible to demonstrate that the technology can ever be completely fossil-free. To reduce emissions, steel companies are first working to change the composition of their input materials. These include increasing the mix of higher quality iron ore, using more scrap steel, mixing in hydrogen, or using biochar. Second, companies are developing technologies to capture emissions for recycling, storage or use in other processes. Whether and how quickly blast furnaces can reduce their emissions on a larger scale is unclear.

According to Vogl et al. (2023), 89 different projects are currently underway worldwide to reduce the emissions of the steel industry. One example of a method that is already widely used is the replacement of coal with biochar from eucalyptus trees in blast furnaces. According to the company behind the technology, Aço Verde do Brasil, CO_2 emissions per metric ton of steel are reduced by 99%.[15] In Sweden, for example, two technologies are being developed that do not involve fossil fuels. FerroSilva uses forestry residues, biogenic carbon, to produce synthesis gas, which in turn is used to produce fossil-free sponge iron.[16] GreenIron H2 intends to use hydrogen gas in the same way as LKAB but states that the process will be significantly more energy- and cost-efficient than the one LKAB is developing.[17] These two firms have only received marginal support from the Swedish Energy Agency and Vinnova (the Innovation Agency), respectively.[18]

15 Rostas (2022) and Iwarson (2023).

16 https://www.ferrosilva.com/en/the-ferrosilva-process/.

17 https://greeniron.se/about/. See Jafri et al. (2022) for a research overview of different decarbonization technologies in the iron and steel industry.

18 SEK 33.9 million to FerroSilva (https://www.energimyndigheten.se/nyhetsarkiv/2024/drygt-300-miljoner-kronor-till-fyra-projekt-inom-industriklivet/) and SEK 17.2 million to GreenIron H2 (https://www.vinnova.se/p/demonstration-of-energy-efficient-and-fossil-free-technology-for-residual-waste-recycling-in-the-steel-industry).

The challenges to achieving profitability

The challenges to achieving profitability in LKAB's and H2GS's planned business stem both from the raw material markets and from the product markets they will operate in.

The problem in the raw material markets is that high-quality ore and steel scrap are strategically important in the steel industry's transition to decarbonization. The demand for these raw materials has therefore increased and will continue to increase. At the same time, these raw materials are only available in limited quantities, which will lead to higher prices as demand increases.

For LKAB this means that the price of their only real resource, iron ore, will be high and almost certainly rise. The more the price of LKAB's iron ore rises, the higher their opportunity cost of producing sponge iron from their own ore. As LKAB has largely streamlined and developed the production of its ore over many years, the consequence is that the premium on their ore will be increasingly higher and the profitability of continuing to sell only ore can be expected to be high. For H2GS on the other hand, the problems in the raw material markets mean that they must compete for access to these raw materials as described above with the risk that they will not get access to all the ore and steel scrap they need or that the prices of these raw materials will be too high to be profitable.

The problem on the product markets is that the premium that companies expect to be able to charge for their fossil-free products risks being lower than what is required to cover the higher production costs. The premium is based on the difference in emissions between, for example, H2GS's steel and steel produced in blast furnaces. This difference multiplied by the price of carbon dioxide gives the premium that can be charged. If the difference in emissions is 1.6 tons of carbon dioxide per ton of steel and the carbon price is EUR 100 per ton of carbon dioxide, the premium is EUR 160 per ton of steel. For H2GS steel to be profitable, the additional cost of producing fossil-free steel must not exceed EUR 160 per ton of steel.

The calculations in Sundén (2024a) show that the margins needed for LKAB's sponge iron venture and the H2GS steel venture to be profitable are very narrow. For the initiatives to succeed, the electricity price must be low and the carbon dioxide price must be high. This is largely confirmed by the research literature in the field, which indicates that hydrogen technologies can become profitable in the long term once the technologies have matured, become more efficient and fallen in price. In particular, this applies to electrolysers, which are still expensive and relatively small in relation to the amounts of hydrogen required. H2GS's investment in a hydrogen-based steel plant can therefore be said to be premature.

Another aspect is that companies seem to be unaware of the fact that emissions from blast furnaces and other emitting technologies can be expected to decrease over time. This means that the premium that can be charged will gradually shrink. For example, in the information material used by H2GS in their communication, they calculate the premium on the basis that the difference in CO_2 emissions is as high as two tons of CO_2 per ton of steel far into the future. Such a large difference in emissions is already too large today, partly because the blast furnaces emit approximately 1.6 metric tons of carbon dioxide emissions on average, and partly because H2GS's "fossil-free" steel is not 100% fossil-free but will lead to relatively large emissions. These emissions emanate from the purchase of inputs in the form of iron ore from Canada and Brazil that is not fossil free, and from the natural gas they will initially use in production. The difference in carbon dioxide emissions on which to base a premium calculation is likely to be at most 1.3 tons of carbon dioxide per ton of steel. Moreover, projections of the carbon price in the future vary considerably, showing prices at the same level as today, around €70 per ton of carbon dioxide to €170 per ton. In other words, there is no consensus on how the carbon price will develop.

To summarize, the price of electricity must be low, the price of carbon dioxide high and the steel industry must fail to decarbonize in order for LKAB and H2GS to succeed with their investments.

Challenges in the electricity market

Four major players, LKAB, SSAB, H2GS and Fertiberia,[19] have announced electricity-intensive production in Norrbotten County, more specifically in bidding zone SE1. According to previously announced plans, the companies' total needs amount to about 20 TWh in 2026, 40 TWh in 2030 and 90 TWh in 2050. LKAB accounts for the largest share of the additional electricity needed, around 80%. Over the past year, all plans have been postponed due to over-optimistic timelines. This enormous increase in demand in Norrbotten County alone should be added to the other increases in demand that can be expected as society becomes increasingly electrified.

The analysis in Sundén (2024b) shows that electricity prices in the Nordic region can be expected to rise sharply if the companies' plans are realized. Electricity consumers in northern Sweden, particularly in bidding zone SE1, will be hardest hit, but the problems will also spill over into Finland and northern Norway when Swedish electricity production is insufficient to cover the companies' demand. Even with assumptions of a major expansion of electricity production, electricity prices can be expected to rise, although not as sharply.

The investing companies can expect to face an electricity price of at least SEK 0.82 per kWh in 2026. Such a price level means that LKAB's fossil-free sponge iron will cost at least 90% more than competitors' sponge iron made using natural gas. An electricity price of SEK 0.82 per kWh also means that H2GS's fossil-free steel will be at least 40% more expensive than competitors' steel without carbon dioxide compensation. With the compensation, the price of the steel is at least 10% higher than the competitors' most expensive steel.

Higher electricity prices in general in the Nordic region, and in particular in Norrbotten and bidding zone SE1, are also forecast by Svenska kraftnät and Energiforsk. In its short-term market analysis from 2022, Svenska kraftnät predicts that the electricity price in bidding zone SE1 will be about SEK 0.82 per kWh in 2027 and in its long-term market analysis from 2024, it expects the price to be about SEK 0.73 per kWh in 2025 and about SEK 0.66 in 2035,[20] excluding grid fees. These increased prices have significant welfare

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[19] Fertiberia is a Spanish fertilizer producer owned by the private equity firm Triton Partners. They plan to locate in Norrbotten County and use fossil-free electricity to produce ammonia and fertilizers. They require 4–5 TWh of electricity per year.

[20] Svenska kraftnät (2022, 2024).

implications for Nordic electricity consumers—households, businesses, and public sectors. Electricity consumers in Finland, northern Norway and northern Sweden experience the greatest negative impact from the companies' investments when electricity prices rise. The higher prices lead to large redistributions of economic value from electricity consumers to electricity producers.

In order to meet the companies' electricity needs, uniquely large investments in both transmission capacity and production capacity will be required. These investments are probably not the most politically important, economically profitable, or commercially interesting for the entities producing electricity. From an electricity market perspective, the companies' plans will thus have a limited ability to generate profitability. This can best be understood in the light of the displacement effects they create by virtue of their size—the currently cheap electricity in northern Norrland has, put simply, attracted investments that are too large. The companies' myopic investment calculations do not seem to have considered that their own investments, or those of other companies, are so extensive that they will have a major impact on the electricity market in general. If all investments are carried out according to plan, electricity prices will rise so much that the investments will be unprofitable. It is therefore inevitable that one or more of the companies will either need to abandon their plans or fail.

How did this situation occur and what should be done?

In the light of our conclusions so far, the following question comes to mind: How did this situation occur? The simple answer is that none of the three major electricity-using companies—LKAB, H2GS, and Fertiberia—are listed on a stock exchange. They are therefore not subject to the normal daily scrutiny of a large number of market and equity analysts. The consequence is that announced plans are not questioned, the information in press releases is not verified, and the reasoning and calculations behind their decisions are not scrutinized in detail. Without a stock exchange listing, society does not receive a market assessment of the companies' plans in the form of a share price that combines all the assessments made by a free market through thousands of independent analysts and investors.

If H2GS had been listed on the stock exchange, its business plan would have been questioned from the moment it was communicated and this would have affected the share price. The reason is that the amount of capital needed to build and operate the H2GS steel plant was unreasonable from the start. The announced capital requirement has in a matter of years risen from SEK 25 billion to produce five million tons of steel initially, to SEK 50 billion in the spring of 2023, to SEK 60 billion in November 2023, to the latest figure of SEK 100 billion communicated in January 2024.[21] In Sundén (2024a), the investment cost of H2GS, based on the scientific literature and actual data from other steel plants being built, is estimated to be at least SEK 79 billion for its facilities alone.

In LKAB's case, the owner is the state, which creates a dual problem. First, LKAB has a significant knowledge advantage over the few officials at the Ministry of Finance who are responsible for the company. It cannot be expected that these officials have either the time or the competence to review LKAB's plans in the way it would have been done if the company had been listed on the stock exchange. It will thus be difficult for a government owner to bring matters to a halt without a signal in the form of a sharp fall in the share price—the result when a company's management launches unrealistic investment plans.

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[21] Augustsson (2024).

Second, the board of LKAB can hardly be said to have been appointed based on the special knowledge required to run a highly competitive international mining or steel company. A review of the members of the boards of the world's largest mining and steel companies reveals, not surprisingly, that a large proportion have very long experience in the mining and steel industry. In addition, the boards include people with considerable experience in the financial sector, which is needed to understand and hedge the financial risks of the business and investments, people with an auditing background to be able to review and challenge the plans presented, and people from manufacturing who understand the customers' perspective. In almost all cases, board members have at least 30 years of experience in the areas in which they operate. The competence and experience profile of LKAB's board members differs significantly from its competitors in almost all respects.

What can be done?

To understand how LKAB and SSAB should have dealt with the challenges of climate change, we must first understand the basic problem from a Swedish perspective. This requires a closer look at SSAB. It is SSAB's carbon dioxide emissions from the blast furnaces in Luleå, Brahestad and Oxelösund that need to be managed and reduced. SSAB has therefore announced that it will switch from blast furnace technology to electric arc furnaces by 2030. The transition to electric arc furnaces means that SSAB's steel will be produced from steel scrap and sponge iron. This transition implies a break in the current value chain between SSAB and LKAB if neither company produces sponge iron. To avoid this, LKAB's iron ore must first be refined into sponge iron so that it can be used directly in SSAB's future electric arc furnaces. However, the responsibility for preventing such a break in the chain is SSAB's, not LKAB's.

The problem is that LKAB is the controlling owner of SSAB (despite an equity share of a mere 10.5%). This means that SSAB does not have full freedom to act. At the same time, LKAB assumes all the risks to reduce carbon dioxide emissions which are in fact SSAB's responsibility. This is clear from the fact that LKAB has taken on responsibility for producing sponge iron when it would be better from both a technical and economic point of view if SSAB produced the sponge iron in direct connection with its future electric arc furnaces. If LKAB assumes the responsibility for sponge iron production, then the risks, financing, and responsibility shift from the public company SSAB to the Swedish taxpayer.

The benefits of allowing SSAB to take responsibility for its own problems are several. First, the company can fully adapt its transition to electric arc furnaces in the way that suits it best. As matters now stand, the company will be entirely dependent on LKAB's ability to meet timelines as well as the technical and financial challenges of the transition. If LKAB's production start is canceled or delayed, SSAB will be forced to find alternative transitional solutions that can be very costly. Second, integrating the sponge iron plants with SSAB's steelworks offers a technical advantage in that sponge iron can be produced and fed directly, i.e., without cooling, to the electric arc furnaces. This provides more optimal energy economy and is therefore the typical way sponge iron is used globally today. Third, such a solution means that SSAB distributes its sponge iron production over three different areas in the Nordic region instead of focusing everything in inland Norrbotten County. This leads to less pressure on the electricity market, which mitigates price effects in Norrbotten and neighboring electricity areas, and the higher demand for labor is distributed between Luleå (on the coast in the very North of Sweden), Oxelösund (116 km south of Stockholm) and Brahestad (on the coast of the Bothnian Bay in northern

Finland) instead of concentrated in Gällivare (inland some 200 km northwest of Luleå). A further advantage is that Svenska kraftnät does not have to expand its transmission capacity to inland Norrbotten County to satisfy the needs of a single company. Finally, the risks of reducing carbon dioxide emissions are placed where they truly belong, namely with SSAB—the company that must decrease its emissions.

Most importantly, SSAB itself can choose whether to produce fossil-free sponge iron or to buy it on the world market and purchase carbon offsets. SSAB can then optimize its transition to fossil-free production as new technologies are developed. Finally, as a listed company, SSAB will be heavily scrutinized by market and stock analysts during this process. The decisions made must therefore be grounded so that the share price is not negatively affected.

The problems and transition of SSAB are neither the responsibility of LKAB nor the taxpayers. Instead, LKAB has its own major challenges that it must manage. The company's focus must be to secure its own transition to fossil-free production, to secure access to ore in the long term and to take advantage of the rare earth metals that are now profitable to mine in the Per Geijer deposit. These three projects are high priority and will cost considerable sums to implement.[22]

The short-term solution would be for LKAB to transfer the sponge iron production plans to SSAB and let SSAB determine the best way to solve its own problems. This implies a requirement for LKAB to sell its ownership stake in SSAB to make the company as independent as possible from LKAB and the Swedish government. Thereby the Swedish taxpayers would no longer be liable to shoulder SSAB's problems. It is reasonable to propose that the Finnish government divest its ownership in SSAB to avoid a situation in which the Finnish government could apply pressure to prioritize the transition in the Finnish town of Brahestad for reasons other than purely business-related ones.

In the long term, the Swedish state needs to review its ownership role in companies such as LKAB. This includes governance, review, and democratic control of the company's operations and plans. A first simple and quick step would be to appoint the board of directors based on criteria that prioritize the necessary experiences and knowledge to run a modern mining company facing intense international competition. In the longer term, it would be valuable for the company to be listed on the stock exchange in order to benefit from the discipline and continuous evaluation of its performance and future plans that a listing provides.

[22] In early 2024, LKAB announced their plans for yet another large project: the extraction of phosphorous from its ore to be used in fertilizer production (Karlgren, 2024).

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