STEEL TECHNOLOGY

STEEL INDUSTRY COMMENTARY

A new steelmaking technology emerges

Steel production is a major source of CO_2 emissions accounting for about 7% of the world total. Emissions largely stem from 70% of steel produced using blast-furnace-basic oxygen furnace technology. During metallurgical processing CO_2 is generated due to the use of coke as a reductant to separate ferrous material from the oxide ore. Coke is a highly effective and cost competitive reductant which cannot be easily substituted. An alternative low-carbon steelmaking metallurgical process, however, is emerging. This is based on applying DRI (direct-reduced-iron) technology but using hydrogen as the active ingredient rather than natural gas/syngas. The key issues surrounding the adoption of the new technology by existing steelmakers are capital cost, the supply of high-grade pelletized iron-ore and the integrated supply of green hydrogen. The last mentioned will require large quantities of low-cost power generated either with renewables or nuclear. Potentially rising carbon prices in Europe and elsewhere will encourage the adoption of hydrogen-based DRI technology. The most advanced projects are both in the northern Swedish region of Norrbotten. They are the H2Green Steel (H2GS) greenfield integrated mill planned near Boden and the HYBRIT Project in Gallivare.

- **DRI technology**: DRI or sponge iron is produced in solid form from iron-ore without melting. Iron-ore, which contains ferrous oxide, is reduced to metallic iron typically with a syngas derived from natural gas (methane) and recycled furnace gas (CO). The temperature at which reduction takes place is about 900 ^{o} C, about half that with a blast-furnace which produces molten pig iron. DRI contains 90-94% Fe and can be used as the feedstock charge for basic oxygen furnaces or electric arc furnaces (EAF) to make steel. The melt is then cast into semis such as slab, bloom and billet. Typically, DRI is compressed into hot-briquetted iron (HBI) which reduces the risk of reoxidation.

- **DRI advantages and disadvantages**: Compared with blast-furnace/basic oxygen furnace (BF-BOF) technology, DRI has the advantages of lower capital and energy costs and a smaller carbon footprint. We believe capital costs might be about half those for a blast-furnace/basic oxygen furnace facility reflecting the absence of a sintering plant (assuming ore fines) and coke ovens and the lower investment cost of the DRI reactor and EAF. However, the capital cost saving only applies on a greenfield comparison. Conversion of an existing BF-BOF facility would involve considerable disruption and incremental capital spending. According to industry sources, the carbon intensity of a syngas-based DRI plant is about 38% less than with a BF-BOF facility mainly reflecting lower operating temperatures for reduction. The disadvantages of DRI are the risk of reoxidation particularly during shipment and the slower rate of production than with a BF-BOF facility. Note, BF-BOFs operate continuously and are capable of producing over 10,000 tpd of melt. Industry sources suggest the optimum rate for DRI facilities is less than 3,000 tpd.

- **Hydrogen reductant**: The new steelmaking technology currently emerging involves applying DRI technology but using hydrogen as the reductant rather than syngas. At high temperatures hydrogen is an effective reductant and has the virtue of not emitting CO_2. For comparison, BF-BOF steelmaking generates around two tonnes of carbon/tonne of steel produced. For upstream operations to be truly carbon free, hydrogen will need to be produced via the electrolysis of water using power generated from renewables or nuclear. Ore production, pelletization and transportation would also need to be decarbonised along with the downstream operations. It should be noted that downstream of metallurgical processing significant quantities of natural gas are used in reheat and heat treatment facilities. Electrical power for rolling mills and other machinery is however probably largely internally generated using waste heat from upstream processing.

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EQUITY RESEARCH

Exhibit 1: Sweden highway map and project locations

Source: Ezilon

HYBRIT

Fossil-fuel steel jv between SSAB, LKAB and Vattenfall: The HYBRIT initiative was established as a joint-venture by the Swedish companies SSAB, LKAB and Vattenfall in 2016 with the aim of investigating the potential for producing fossil-fuel free steel in Sweden. A joint-venture company, HYBRIT Development AB, was incorporated in 2017. SSAB (SSABa:ST) is a leading flat-rolled steel producer in Europe with major upstream and downstream operations in Sweden and Finland plus in the US. Steelmaking capacity is around 8.8m tpy currently.

LKAB is owned by the Swedish state and is the only major source of iron ore in Western Europe. Deliveries in 2020 were 28.5 tpy of which 87% were pellets for direct furnace feed. In total tonnage terms LKAB ranks very much as a mid-tier iron-ore concern on a world scale. It does however have a very strong niche in the seaborne export pellet market where it ranks number two to the Brazilian major, Vale. Mining and pellet operations are located in the northern Swedish region of Norrbotten at Kiruna, Malmberget and Svappavaar. Vattenfall is multi-national power generator owned by the Swedish state. It is the leading power generator in Sweden and one of the largest in Europe. It has major hydro power operations in Norrbotten. The three members of the HYBRIT joint-venture with interests in steel, iron-ore mining and power have excellent credentials for a fossil-fuel free steelmaking operation.

Pilot hydrogen-fuelled DRI project at Luleå: The HYBRIT hydrogen-fuelled DRI project at Luleå 900 km north of Stockholm is at the pilot production stage. A timeline to commercial production has been established. The Luleå plant was inaugurated in late August 2020. Construction of an underground hydrogen storage facility is underway adjacent to the plant. This Test DRI production is expected by the joint-venture to be undertaken between 2022 and 2024.

Commercial DRI production in 2026: The HYBRIT joint-venture has indicated that it intends to commence commercial production in 2026. The intention is to establish a new 1.3m tpy DRI plant Gallivare/Malmberget about 230 km north of Luleå and close to LKAB's iron-ore mines and pellet facilities. Production of 2.7m tpy of DRI is expected by 2030. In tandem, SSAB's integrated Oxelösund site 120 km southwest of Stockholm is expected to convert from BF-BOF to EAF steelmaking in 2025. Conversion of the BF-BOF facilities to EAFs at Luleå Sweden and Raahe Finland is scheduled between 2030 and 2040. According to the joint-venture, the HYBRIT project once fully commercial will have the potential to cut CO_2 emissions by 10% in Sweden and 7% in Finland.

H2 GREEN STEEL

H2GS AB founded by Vargas Holdings in August 2020: H2 Green Steel (H2GS AB) was founded in August 2020 by Vargas Holdings AB, a Stockholm-based private equity concern. Vargas itself was established in 2014 by two Swedish entrepreneurs (Carl-Erik Lagercrantz and Harald Mix) for the purpose of applying innovative and potentially disruptive technology to mature industrial sectors such as steelmaking. Sustainability is a key area of focus.

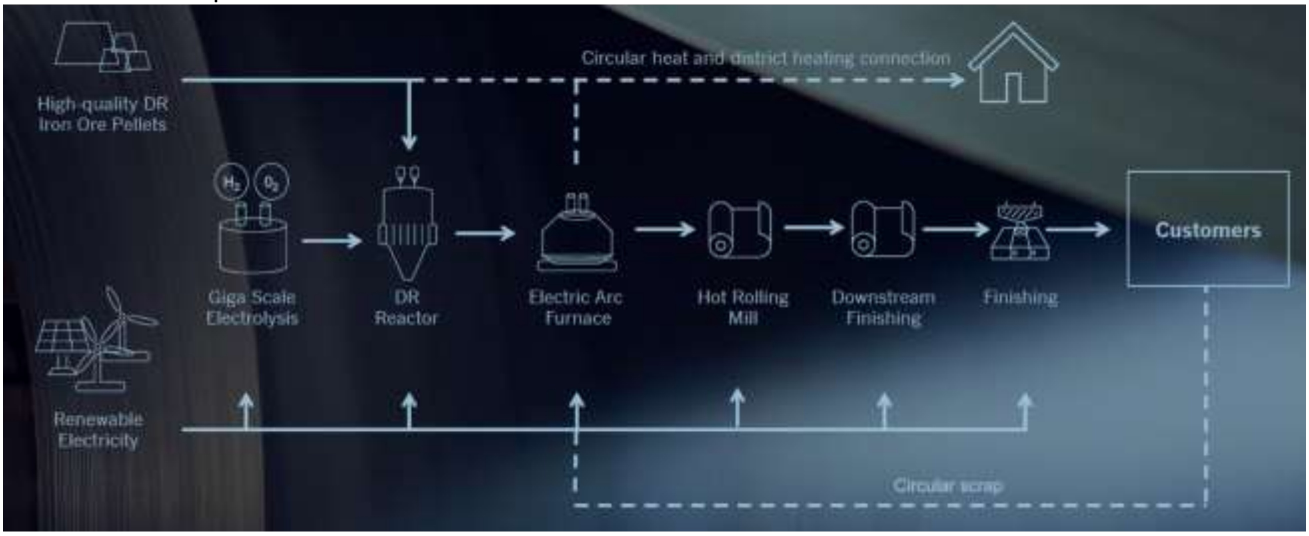
Vargas is an influential private equity concern which was also the founder of Northvolt lithium-ion battery business:

Interestingly, Vargas was one of the founding investors in Northvolt AB. So far this is the most advanced indigenous lithium-ion battery venture in Europe with its plant in Skelleftea and its R&D operations in Vasteras in northern and central Sweden, respectively. The Executive Chairman of H2GS AB is Carl-Erik Lagercrantz while the CEO is Henrik Henriksson. The latter was previously the President and CEO of the Scania Group, a highly regarded company technically, commercially and financially in the heavy truck field.

Ground-breaking announcement in February 2021---------: In a pioneering move in February 2021 H2GS presented its H2 Green Steel project. Located at Boden 35 km northwest of Luleå, the project is both ambitious and impressive technically in terms of scope, scale and the application of advanced technology. It is not an exaggeration to refer to the H2 Green Steel project as revolutionary in steel industry terms. While it draws inspiration from the HYBRIT project in terms of proving the viability of hydrogen-based DRI, the H2 Green Steel project is far broader in scope. A key driver for the project is the desire across manufacturing industry to erase the carbon footprint of finished products. For many products steel is a major component of the commodity mix. A heavy truck, for example, weighs about six tonnes of which five are steel.

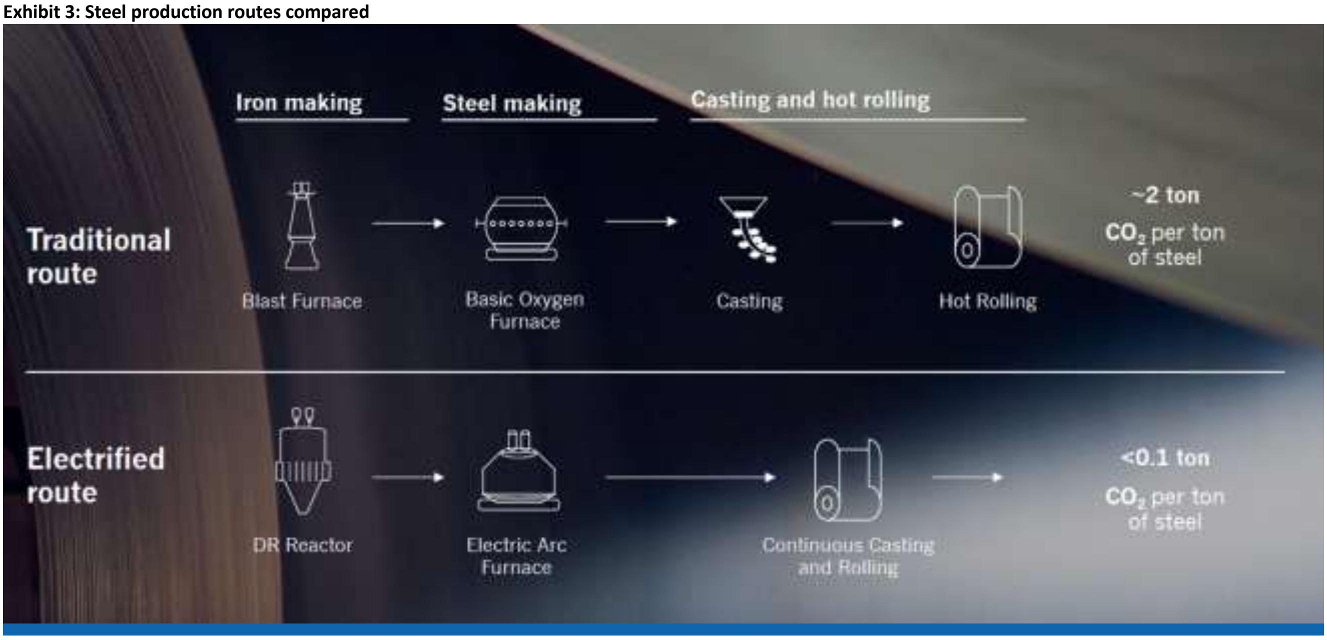
-------concerning a 5m tpy greenfield fully integrated mill using carbon-free technology: H2GS is planning nothing less than a greenfield, large-scale fully integrated flat-rolled steel mill from metallurgical operations to downstream processing using carbon-free technology. Production capacity will be 5m tpy of hot-rolled coil (HRC). By steel industry standards the hot-strip capacity offers excellent critical-mass on one site. We believe the H2 Green Steel project is the most ambitious investment in the European steel industry since the 1960s. Certainly, no greenfield integrated steelworks and hot-strip mills have been constructed in Western Europe since that time.

Exhibit 2: H2 Green Steel production route



Source: H2GS AB

Exhibit 3: Steel production routes compared



Source: H2GS AB

Backward integration into hydrogen production: Significantly, operations upstream will be integrated backwards into hydrogen production applying electrolysis technology linked to renewable power obtained from the grid. The electrolyser will have giga-watt capacity (800 MW) and according to H2GS will be substantially larger than any other in use currently. We believe the largest electrolysers currently being planned elsewhere currently are no more than 100 MW. Hydrogen will be used to produce DRI which in turn will provide EAF feed along with scrap, as discussed previously. The DRI facility will also be far larger than any currently operating and will use pellet feedstock from LKAB.

Integrated continuous casting and hot-strip production: Downstream of metallurgical processing all operations will be sequential and continuous. This helps minimise heat loss, work-in-progress, internal logistics and material handling. Unlike in a conventional mill where slab is cast and then with a lag of several weeks rolled, hot-strip will be produced in one continuous casting and rolling process thereby eliminating a major bottleneck. The hot-strip provides the feedstock for the downstream rolling and cold working operations. A key feature of the planned H2 Green Steel mill is that all stages from upstream to downstream will be electrified. AI (artificial intelligence) technology will be widely applied in a quest to optimise performance.

Production scheduled to start in 2024 with full capacity working by 2030: H2GS's timeline for construction of the planned steel mill appears challenging bearing in mind the lead time for obtaining permits, FEED (front end engineering and design) and equipment procurement. The aim is to commence construction in the first half of 2022 with the production start-up following in 2024. H2GS is aiming for production of 2.5m tpy by 2026 and 5.0m tpy by 2030.

Economics supported by upward trend in carbon prices: H2GS has not divulged details of plant economics but perhaps not surprisingly has intimated that it expects the cost structure to be competitive. This possibly applies particularly in view of how it expects carbon pricing to evolve in Europe over the balance of the decade. As H2GS has noted, steel producers have benefited from the issue of free carbon credits under the EU ETS (emission trading system). Should the regime change, as seems likely, the cost of carbon will either have to be absorbed by the steel industry or passed onto customers in higher prices. H2GS suggests that a carbon price approaching €100/tonne (presently about €40/tonne) would not be fanciful by 2030. Given that the average light vehicle uses about a tonne of steel which generates around two tonnes of carbon in production, the cost penalty could potentially be approaching €200/vehicle. Based on early June 2021 HRC prices in Europe of about €1,000/tonne, carbon at €100/tonne would imply a price rise of 20% (two tonnes of carbon).

As far as the cost structure of H2 Green Steel is concerned, we see a number of potential positives as follows:

- Large-scale operations should offer scope for economies of scale providing high utilisation rates can be achieved.
- Potentially high labour productivity compared with conventional mills reflecting a simpler industrial structure, high levels of automation and continuous operation. H2GS has suggested that output/head should be about 3X that of a conventional mill.
- Proximity to LKAB pellet facilities with an easy link of around 200 km to the planned H2GS mill by rail.
- Avoidance of costly operations in a conventional plant. We are thinking here particularly of the coke ovens and blast-furnace. The elimination of the need for coke in steelmaking potentially saves about €163/tonne of steel based on a price of €325/tonne and a coking rate of 500 kg/tonne of pig-iron produced. Partly offsetting the saving on coke, we believe, could be higher costs for the ore charge given the need for DR pellets rather than cheaper iron-ore fines or lump. There are of course also major issues surrounding power usage and the cost of power.

WHAT ABOUT POWER?

Strong bonds between ferrous material and oxygen atoms require a lot of energy to break: The underlying challenge in producing pig-iron is that the bonds between the ferrous material and the oxygen atoms in iron-ore are very strong and need a lot of energy to break. Coke performs this task very effectively but at the expense of high carbon emissions. The alternative approach using hydrogen-DRI eliminates the emissions (assuming hydrogen produced by electrolysis using renewable or nuclear power) but still requires a heavy input of energy, albeit in a different form. The energy requirement is effectively shifted to the generation of hydrogen.

Huge consumption of electrical power: A prospective H2 Green Steel mill will consume a huge amount of electrical power. To put power requirements into perspective Midrex Technologies, a leading supplier of DRI technology, has suggested that a 1.8m tpy DRI facility would require more than 200 large offshore wind turbines. A 5.0m tpy plant might therefore need about 600 turbines, an enormous wind farm by current standards. We believe, in fact, that H2 Green Steel could evolve as the largest power consumer in Sweden with the principal areas of use being the electrolysis plant, the EAF and the downstream processing operations. With electricity being such an important input, its price is critical to the economics of the H2 Green Steel project. As suggested earlier, economics for planned H2 Green Steel plant will probably be at least partially underpinned by a rising price of carbon. This, of course, implies higher steel prices than those presently prevailing other considerations being equal.

Norrbotten well-endowed with power: Historically, Sweden has benefited from competitive power particularly in the region of Norrbotten, where there has traditionally been a surplus of power reflecting major hydro developments along the Lule River. H2GS has a positive view of power availability in Norrbotten prospectively given the availability of large quantities of hydro plus major wind power developments. The scheduled start-up of the Olkiluoto 3 1,600 MW nuclear reactor in Finland in 2022 will also effectively boost power supplies in Norrbotten by reducing or possibly eliminating the need to export power. It needs to be remembered, however, that power needs will be rising strongly in Norrbotten and Vasterbotten immediately to the south over the next few years not only due to the H2 Green Steel project. This reflects the development of the HYBRIT project and the electrification of LKAB's operations together, in all probability, with those of other concerns in the metallurgical field such as Boliden.

FINANCING AND STOCKHOLDERS

$105m raise in Q1/Q2 2021 raise through a marquee list of shareholders: H2GS AB raised $105m in the first and second quarters of 2021 for the initial funding of the H2 Green Steel project. The raise was handled by Morgan Stanley. In addition to the founding Vargas Holdings AB, H2GS has a marquee shareholder list of corporates, investment funds and high net worth individuals interested in sustainable development. In terms of the corporates and investment funds the key shareholders excluding Vargas Holdings include the following:

- **Scania AB**----One of the world's leading heavy truck manufacturers headquartered in Södatälje (Stockholm) and a subsidiary of VW's heavy truck arm, Triton. Note, VW also has a 20% stake in the lithium-ion venture, Northvolt AB.
- **Mercedes-Benz AG**---The newly constituted car and van entity of the former Daimler Benz. Mercedes aims to use carbon-free steel in its products from 2025.
- **Marcegaglia Spa**----Privately owned Mantova-Italy headquartered downstream steel processor. It is the largest independent in this field both in Italy and globally.
- **SMS Group GmbH**---Düsseldorf-based leading supplier of metallurgical equipment and technology. The company is particularly strong in the mini-mill field, and we believe is a potential supplier of equipment to H2 Green Steel.
- **AB Stena Metall Finans**---- Finance arm of the Sweden-based Stena Metall metals, oil trading and recycling group.
- **Exor NV**------Milan-listed investment holding company owned 53% by the Agnelli family.
- **FAM**---Sweden-based investment fund owned by three Wallenberg Foundations.
- **IMAS**-- Investment vehicle for the INGKA Foundation which through INGKA Group owns and operates the Ikea organisation.
- **Bilstein Group**----Privately owned and Germany-based auto component supplier, particularly for the aftermarket.
- **Altor Fund**----Stockholm-based private equity fund organisation focused predominantly on investments in medium-sized companies in the Nordic Region.

Harald Mix, the acting Chairman of H2GS AB is a founder and partner in Altor Equity Partners.

- **EIT InnoEnergy**---- European Union funded organisation aimed at promoting sustainable energy development across Europe and beyond with the focus on battery technology, green hydrogen and solar power. Since inception in 2010, more than €600m has been invested in sustainable energy development.

€2.5bn funding round scheduled for Q4 2021: H2GS has indicated that it will be seeking another funding round in the fourth quarter of 2021. Not surprisingly at €2.5bn this will be in a different ballpark to the earlier one. It will be used to finance the first phase of the H2 Green Steel project in the lead up to the production start-up in 2024. Of the total, €0.75m is scheduled to be equity and the balance project debt financing. Financing is probably comfortably underpinned given the apparent enthusiasm for the first round, the growing interest generally in sustainable energy production and usage and probable European Investment Bank involvement. Morgan Stanley will continue to be engaged in equity financing while Societe Generale will act as overall financing co-ordinator, according to H2GS AB.

ARCELOR MITTAL HAMBURG

Steelmakers widely investigating the potential to convert to DRI technology: There probably is not a major steelmaker, in the western world at least, that is not investigating the potential to convert from BF-BOF to hydrogen-based DRI production. Clearly, those producers already applying DRI technology using natural gas as the reductant are in the strongest position to undertake development. As we have noted, a conventional natural gas/syngas-DRI facility is capable of achieving very significant reductions in CO_2 emissions compared with BF-BOF technology.

Arcelor Mittal Hamburg planning a 0.1m tpy hydrogen-based DRI facility: One of the more high-profile DRI development projects is at Arcelor Mittal's Hamburg billet operations. The site contains a 0.98m tpy DRI plant which uses natural gas/syngas to process iron-ore pellets. A project in conjunction with Midrex is currently ongoing to produce 0.1m tpy of steel using hydrogen-based DRI technology. Interestingly, Arcelor Mittal/Midrex have already experimented with operating the DRI plant with varying charges of hydrogen up to approaching 100%. Apparently, for charges up to 30% hydrogen can be used without modification of equipment. Higher levels of hydrogen intensity do, however, require some minor modifications. Significantly, the natural gas: hydrogen mix can be changed relatively quickly.

Plan based on using a combination of blue and green hydrogen: Arcelor Mitall is planning to operate the Hamburg plant on a combination of blue and green hydrogen. The former will be obtained directly from natural gas and industrial syngas in combination with carbon capture and storage to offset CO_2 emissions. Syngas will be derived from furnace waste gas. Green hydrogen will be produced through the electrolysis of water probably using power generated by North Sea offshore wind farms. The use of blue hydrogen addresses potential concerns regarding power availability and cost associated with green hydrogen.

IMPLICATIONS FOR COKING COAL

Coking coal is the most profitable product line: We estimate that world coking coal production (all types including pulverised coal for direct furnace injection) is currently running at about 1.1m tpy. This assumes BF-BOF pig-iron output of about 1.35bn tpy and an average blast-furnace coking rate of 600 kg/tonne of pig iron. The implied blast-furnace consumption of coking coal is 810m tpy. In addition, we think there could be another 300m tpy or so consumed as coke in foundry furnaces, ferro-alloy production, iron-ore pelletization and iron-ore sintering operations. In total, coking accounts for about 15% of world coal production. Importantly, coking coal tends to be the most profitable coal product line. Typically, hard coking coal sells at a premium of $50/tonne plus to steam coal while there is little by way of incremental cost except a modest amount for washing. The premium reflects the absence of substitutes to coke as a reductant and the relative scarcity of high quality hard coking coal supplies.

Long investment lead times imply that coking coal usage is not under threat near to medium-term------The key question now for the coal industry is its potential vulnerability near to medium term to a loss of the lucrative coking coal business due to the widespread adoption of hydrogen-based DRI production technology. We think the answer is not very vulnerable. The main reason quite simply is the long lead time to either invest in new greenfield facilities as in the case of H2GS or possibly more likely to convert existing metallurgical operations to hydrogen-based DRI and EAFs.

An intermediate strategy might be to use DRI as either blast-furnace or basic oxygen furnace feed. Both approaches are in fact already followed. Charging DRI in blast-furnaces enables coking rates and therefore CO_2 emissions to be reduced while boosting the output of metal. Lower operating temperatures may also reduce the need for furnace relines. According to Midrex, the DRI blast-furnace charge can be up to 30% without equipment modification. Blast-furnace output can be increased 8% for a 10% DRI charge. In the case of basic oxygen furnaces, DRI charging acts as a substitute for coolant scrap. Shortages or high scrap costs can favour using a high DRI charge. Given the absence of tramp elements DRI might also offer a purer form of furnace feedstock.

It should be noted that the cost of fully converting an existing BF-BOF facility to a hydrogen fuelled DRI and EAF plant would be considerable in terms of capital spending and disruption to output. There may also be higher cost inputs to consider. The €2.5bn price tag of phase one of the H2GS's planned Boden facility throws some light on the costs involved. We also know that the capital cost in recent years of Voest Alpine's 2m tpy natural gas fuelled DRI plant in Corpus Christi, Texas was $1.0bn. An EAF, hydrogen plant and logistical facilities would add considerably to this sum. One of the big unknowns here is the prospective cost of carbon. It could be that costs will rise so high that steelmakers have no alternative to investing in DRI. In practice the only alternative might be to close.

--------but writing is on the wall long-term: Given the lead time issue, we think that the coking coal market will not be significantly impacted by hydrogen-based DRI in the current decade and probably for most of the 2030s. One development that could occur to slow the adoption of DRI would be technical issues with the new H2 Green Steel plant. At this stage we do not know how the new technology will perform at high volume. Reducing the iron oxides could, for example, prove more difficult or costly than presently expected. Long-term, which we will define as post 2040, the writing, however, is clearly on the wall for BF-BOF steelmaking and indeed coking coal.

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