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Green steel: the road to net zero





Hydrogen passes the test for heating steel. Linde and Ovako engineers at the pit furnace, in Hofors, Sweden

Introduction

The world is getting serious about reducing CO_2 emissions. As nations globally suffer the effects of a warming atmosphere, policymakers are moving to implement strategies for net zero carbon by 2050. For some industries, the path to achieving this is relatively clear. For others—the so-called 'hard to abate' sectors—it is more challenging because there are few low-carbon alternatives to today's way of operating. One of these sectors is steelmaking, which relies on fossil fuel for process heat and as a feedstock.

Switching to low-carbon operations seems particularly challenging for steel, but there are promising options ahead. Renewably produced or 'green' hydrogen, which is increasingly being seen as the key to powering other hard-to-abate industries, looks set to eventually liberate steel from its carbon habit.

And although green hydrogen is not yet a cost-effective proposition for the steel sector, a range of technologies can already help the industry reduce its emissions while hydrogen's costs fall. This white paper, prepared in association with Linde, the leading industrial gases and engineering company, aims to show not only that there is a realistic pathway for steelmaking to reach net zero emissions, but also that it can be achieved by 2050.



The challenge facing steel

There is no net zero without decarbonizing the steel industry. A key material for industries such as construction and automotive[i], the world consumed close to 1.8 billion tonnes of crude steel even under the dampened-down demand conditions of 2020.[ii] Yet steelmaking is a carbon-intensive process, accounting for 7-9% of global greenhouse gas emissions.[iii]

Integrated steel mills that use blast furnaces and basic oxygen furnaces (BF-BOF) to process iron ore get 89% of their energy from coal and 3% from natural gas.[iv] Primary steel production is heavily reliant on coal-based coke as a reducing agent for iron ore, plus natural gas for process heat. This means an average 2.3 tons of CO_2 are produced for every ton of BF-BOF steel.[v]

Integrated mills produce 70% of the world's steel but emit 90% of the industry's carbon.[vi] Steel minimills using electric arc furnaces (EAFs) to process scrap and direct reduced iron (DRI) have lower emissions, of 0.6 tons of CO_2 per ton of steel[vii], because they use less coal (11%) and more gas (38%). Emissions from their 50% electricity use [viii] depend on the grid.

Decarbonizing steel is a challenge not just because of the extent to which fossil fuels are baked into the production process, but also because of cost. "It's hard to abate in the sense that it's very, very expensive," comments Joachim von Scheele, Global Director of Commercialization at Linde.

The cost conundrum

With cheap, unlimited supplies of renewable energy it would be possible to purify iron ore directly via electrolysis, von Scheele says. However, current electrolysis technologies are still at an early stage of development[ix] and the amount of energy that might be required to power them could be prohibitively expensive.

Cost is also the main barrier to what currently looks like steel's best option for a long-term low-carbon fuel source: green hydrogen. Produced from renewable energy via the electrolysis of water, green hydrogen can be used as a source of heat and power, and as an auxiliary reducing agent in BF-BOF production. Plus, it can act as the sole reducing agent for DRI.[x]

An advantage of green hydrogen is that there is global interest in developing the fuel for a range of applications, from feedstock production to transportation.[xi] This should ultimately lead to a reduction in the cost of green hydrogen, although today "it is up to five times more expensive than natural gas mainly due to power costs," says von Scheele.

When green hydrogen is not feasible/available, significant reductions in emissions can be achieved through the use of blue hydrogen. Clean hydrogen (which entails both green and blue hydrogen) could become more competitive not only through economies of scale but also if the price of carbon goes up. A high carbon price would also make it more profitable for steelmakers to adopt low-carbon processing methods. Thus, the potential for full decarbonization of the steel industry is closely related to the cost of both clean hydrogen and carbon. The former is expected to fall while the latter is expected to rise, but there is no clear timeline for either trend.

In the meantime, steelmakers will be understandably loath to invest in full decarbonization. Unlike sectors such as aviation, where customers may be willing to pay a premium for low-carbon options, "the steel industry isn't typically a high-margin business," says David Burns, Vice President of Clean Energy Development at Linde.

A growing technology toolbox

The good news is that the industry already has technologies that can help reduce emissions through improved efficiency—and are able to support a move to clean hydrogen in the future. Foremost among these is the use of oxyfuels for ladle preheating. Oxyfuel technologies such as Linde's OXYGON product line use pure oxygen instead of air for combustion.

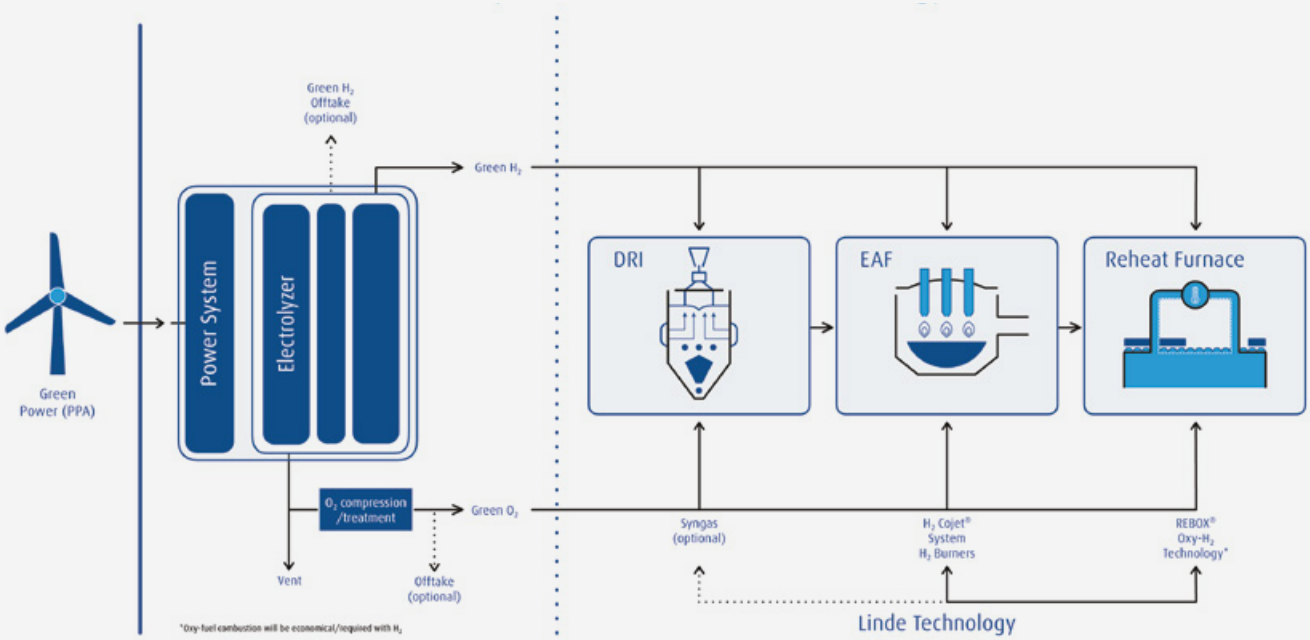
Because airborne nitrogen is no longer part of the process, "you reduce flue gas volumes and you intensify the combustion, creating a more efficient heating process," says David Muren, Linde's Europe, Middle East and Africa Director of R&D Metals and Combustion.

Similarly, Linde's REBOX HLL technology replaces up to 75% of the air in steel reheating furnaces with oxygen, improving thermal efficiency, cutting fuel consumption by up to 25% and reducing exhaust gas volumes by more than 50%.[xii] Applying these proven oxyfuel and hot oxygen technologies to steelmaking could cut carbon emissions from some processes by up to 60%, potentially saving the steel industry 200 million metric tons of CO_2 a year, Linde has calculated.[xiii] Such savings could be even larger when using "green oxygen", meaning oxygen produced with renewable energy.

Furthermore, this technology is completely compatible with a low-carbon energy system and would in fact benefit from on premise green hydrogen production, since it could take advantage of the oxygen produced by electrolysis. Elsewhere, technologies such as the Linde CoJet® systems used to decarbonize the chemical energy input into EAFs have been found to work optimally with hydrogen.[xiv]

Mapping the path to net zero

Schematic of a low-carbon DRI-EAF steel plant, based on available technology.



Source: Linde.

For steelmakers today, "it's hard to invest in an electrolyzer knowing that the steel they will produce will be more expensive, compared to the rest of the world," says Pravin Mathur, Linde's Executive Director for Metals, Combustion and Energy.

But the fact that there are several emissions-reducing technologies that can be deployed now means steelmakers do not need to wait for shifts in carbon pricing or green hydrogen costs to begin decarbonizing their operations. And in some cases, the technologies available today result in efficiency gains that effectively make them revenue neutral.

Over the longer term, green hydrogen costs are expected to fall significantly owing to demand from earlier-adopting sectors such as heavy goods transportation. In parallel, CO_2 costs are likely to rise, with analysts expecting EU carbon pricing to hit €90 a metric ton by the end of the decade. At this point, Mathur says it may become cost effective for steelmakers to start investing in green hydrogen infrastructure.

All of this is predicted to happen against a backdrop of rising renewable energy capacity and falling clean electricity costs as nations worldwide stimulate investment in pursuit of net zero targets. "If you get green power, you can make the hydrogen required for downstream processing," Mathur says. "Fundamentally, it comes down to getting green power."



Using oxyfuel instead of air for ladle preheating increases the overall efficiency of the heating process

Case study: Ovako

While the steel industry's transition to full decarbonization could take decades, some players are proving it is possible today. Ovako, a European manufacturer of engineering steel for bearings, transportation and manufacturing, has cut emissions by 55% since 2015 and will become fully carbon neutral in 2022 thanks to a combination of low-carbon technologies and certified carbon offsets.

It is also in the process of building a green hydrogen plant in collaboration with partners. The SEK 180 million ($21 million), 20 MW project, in Hofors, Eastern Sweden, will produce 3,500 cubic meters of green hydrogen per hour on completion in 2022, powering not only Ovako's heating before rolling operations but potentially also a fuel cell-equipped truck fleet.

Göran Nyström, Executive Vice President of Marketing and Technology at Ovako, says trials developed with Linde in 2019 and 2020 showed hydrogen could replace propane as a burner fuel without any loss of performance. Although hydrogen is less energy dense, "the molecules flow through the tubes much more easily and quickly than propane does," he says. "So, we can burn with the same energy. Within a second we can switch from one fuel to the other."

The Hofors electrolyzer plant will be powered by a low-carbon wind, hydro and nuclear electric mix procured under a power purchase agreement with Vattenfall, he says. Having the electrolyzer on site will mean the hydrogen will not have to be stored or transported, keeping costs down. The investment in the electrolyzer could be partly offset by the sale of excess hydrogen to other industrial users.

Another potential income stream could be to provide demand response services to the grid. Retaining the ability to switch back to propane fuel would allow the steelmaker to dial down its electrolyzer production if needed, helping to overcome grid constraints. Finally, "we will have benefits over time with increasing penalties for CO_2 and a rising preference by customers to place orders with companies like us," says Nyström.

Outlook and conclusions

When it comes to reducing emissions, Ovako is fortunate on three counts. It employs EAFs, so its operations are already more climate-friendly than those of BF-BOF steelmakers. It also processes scrap metal, so it does not have to worry about emissions from iron ore mining and transportation.

And it operates in a market with high carbon prices and large amounts of relatively cheap low-carbon electricity, strengthening the business case for decarbonization. Nevertheless, the fact that Ovako is aiming to achieve net zero emissions by next year is encouraging. It shows that net zero is possible for the steel industry using today's technology.

One lingering concern for the industry is that decarbonization will drive up the cost of production and make mills less competitive than carbon-emitting rivals.

Here again, though, there are encouraging headwinds. In Europe, which has the world's highest levels of carbon pricing, there has long been talk of a border adjustment mechanism that will level the playing field between native steelmakers and importers, adding cost to higher-emissions products. At COP 26, negotiators agreed on rules for implementing Article 6 of the Paris Climate Agreement, which will pave the way for more effective cross-border cooperation on carbon markets moving forward.

Meanwhile China, which accounted for almost 57% of global steel production in 2020, this year launched a carbon market of its own. The exact path to net zero steel production may still be unclear, but the direction of travel is now clearly signposted.



Replacing up to 75% of air with oxygen in steel reheating furnaces improves thermal efficiency, cuts fuel consumption by up to 25% and reduces exhaust gas volumes by more than 50%

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