On track for green steel making

Reducing CO_2 emissions is the name of the game in steelmaking, and hydrogen has a key role to play, says **Lynn Gorman***

IT is widely acknowledged that mankind must limit atmospheric temperature rise. Carbon dioxide (CO_2) has been identified by environmental experts as an important contributing element in climate-change science, and that its emissions must be reduced dramatically. The steel industry is known to be a major CO_2 emitter. This is not a news flash. The worldwide steel industry is among the largest contributors to atmospheric CO_2, emitting nearly three billion tons of it at a level of about 7% to 8% of total CO_2 emissions. Yet, positively, iron and steel production is also among the most promising opportunities for measured and impactful decarbonization, and steelmaking is a viable place to start. Why? Because the industry is of strategic national importance and awareness in all countries, there are identified and actionable solutions to reduce CO_2 emissions, there are technologies identified to accomplish this, and the governments are major end users. Governments can encourage CO_2 reduction for iron and steel using the techniques of levying taxes, fees, subsidies, and laws.

Transitioning from legacy to modern steelmaking

The steel industry has already made significant progress in this effort, which has resulted in some degree of decarbonization. As the industry has switched investment from the legacy steelmaking technologies of the blast furnace and the basic oxygen furnace (BOF) to the current preferred technology of the electric arc furnace (EAF), the steel industry has become significantly decarbonized and the plants have become smaller, cleaner, and are consuming less energy. While EAF facilities primarily use scrap steel to make new steel, they must add additional iron molecules to the process, such as DRI (direct reduced iron), sponge iron, or HBI (hot briquetted iron), various terms for a raw material to augment recycled steel in EAF production. DRI materials are made by reducing iron ore using CO (carbon monoxide) or hydrogen or a mixture of the two. Traditionally, DRI has been produced using a synthesis gas, which is generated from natural gas and consists of a blend of CO and hydrogen. DRI can also be made with pure hydrogen, and pure hydrogen is a more powerful reducing agent than CO and provides improved kinetics. It is believed that DRI production using pure hydrogen could result in production enhancements.

Encouragingly, the war for greener steelmaking in the 21st century is being won. According to David Wolff, territory manager at Nel Hydrogen, EAF steelmaking sets the stage for the next steps in the CO_2 reduction mission. "EAF-based plants are virtually all that's currently being built for steelmaking," said Wolff. "There are nearly zero new investments in blast furnace or BOF capacity and at best, these facilities are being maintained with some conversions underway to cleaner technologies. As the industry evolves from blast furnace and BOF to EAF, steelmaking emissions are being lowered from 2.25 tons of CO_2 per ton of steel to less than 1.5 tons of CO_2 per ton of steel, or 30%. So, carbon's place in steelmaking is narrowing."

Traditionally, the steel industry has used coal and coke for fuels for heat, to make CO as a reducing gas, and as a strengthening additive in steel production. For every molecule of carbon consumed in steelmaking, a molecule of CO_2 is produced, so one ton of coal or coke results in almost four tons of CO_2 production. As a result of the evolution in production technologies, from blast furnace and BOF to EAF, for each ton of steel produced in the decade from 2011 to 2020, an average of about 1.85 tons of CO_2 was emitted.

This decarbonization effort has been underway for some time. Coal as a fuel has been progressively replaced by natural gas

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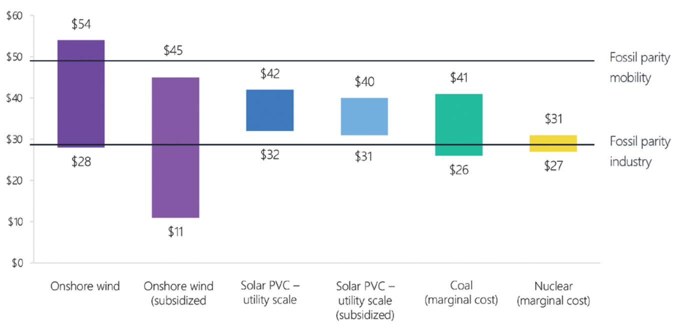
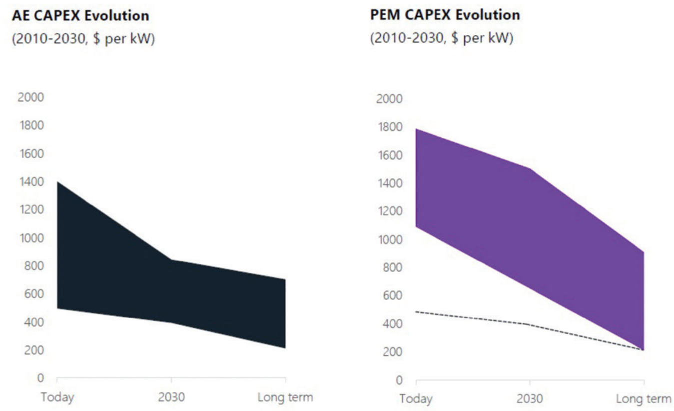
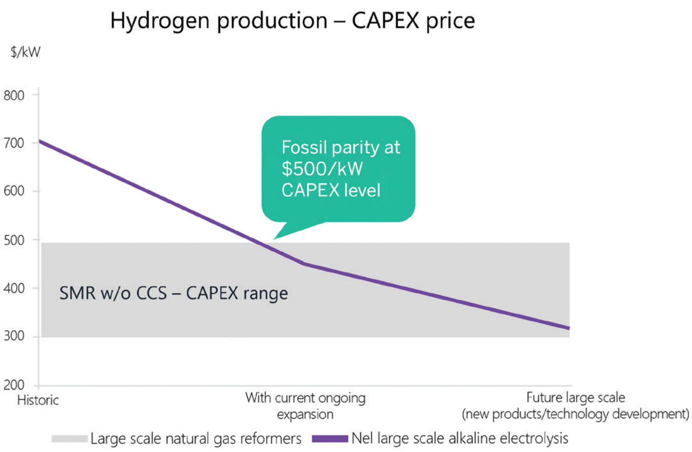


This bar chart illustrates the levelized cost of wind and solar energy along with coal and nuclear today. Note the dramatic performance of the renewables against legacy technologies. These low costs are making it possible for water electrolysis to yield highly cost-effective hydrogen for the steel industry.

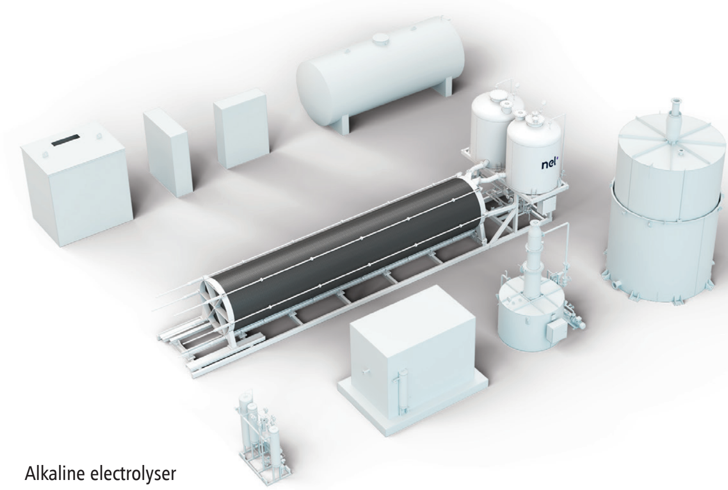


Sources: IEA

These graphs illustrate the lower CAPEX slope comparing alkaline electrolysers with PEM electrolysers over time. Note that both technologies will result in $300 per kW CAPEX for hydrogen generation by 2030.



This graph shows the expected decline in electrolysis CAPEX and how that compares to the similar CAPEX using steam methane reforming. Note that it becomes competitive at $500 per kW and better at $300 per kW, which is the expected goal.



Alkaline electrolyser

and electricity in many applications.

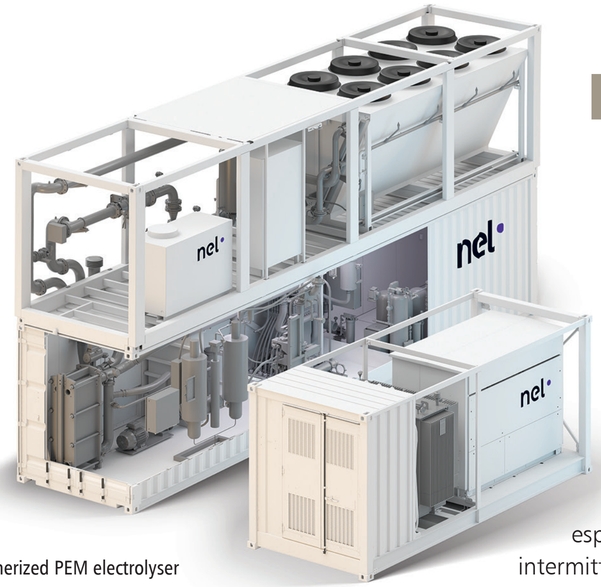
"The next step in the mission for greener steelmaking is introducing zero carbon hydrogen to the mix," said Wolff. "Soon, it's predicted the industry will be using hydrogen-enhanced EAF steelmaking which will make it possible to continue the reduction in carbon emissions initiated by the conversion of blast furnace and BOF to EAF furnaces fueled with scrap and DRI. EAF steelmaking enhanced with hydrogen will use hydrogen-derived DRI and hydrogen-enhanced electric arc furnaces with near-zero CO_2 emissions per ton of steel."

Hydrogen steelmaking will grow with supporting infrastructure

Longer term, then, green steelmaking is likely to include hydrogen which can complement electricity and replace coke and coal as fuel. Hydrogen-enhanced steelmaking can drive down emissions significantly. While the conversion from blast furnace and BOF to EAF reduced carbon emissions by about 30%, hydrogen steelmaking can reduce CO_2 emissions by a total of about 90% compared with traditional blast furnace and BOF steelmaking. However, to reach that level requires massive production of green hydrogen at a cost that's acceptable to steelmakers. As such, there needs to be enough green electricity produced to make that hydrogen, the industry needs to use green hydrogen for direct reduction of iron ore to make DRI using hydrogen only, and there needs to be green hydrogen fuel to augment melting of carbon-free DRI and recycled steel in the EAF.

"That supporting infrastructure isn't quite there yet – however, progress is underway," said Wolff. "For example, Nel Hydrogen received a purchase order to participate in the first large scale plant to demonstrate these symbiotic technologies working in concert with each other to support this revolution in green hydrogen steelmaking."

The project in which Nel is participating is one that many of us in the steel industry have read about – the HYBRIT project in Sweden. It's a multi-stage initiative starting with a pilot plant for demonstrating green steel production. Nel is providing a 4.5 megaWatt energy input alkaline electrolyser for this pilot plant stage. It was announced in mid-August that HYBRIT had shipped its first commercial shipment of green steel to Volvo for auto manufacturing. Breaking news is that Mercedes is in discussion to be the second automaker client for HYBRIT.



Containerized PEM electrolyser

More news will be forthcoming as the project advances.

Making hydrogen available at a realistic price

Hydrogen can provide both thermal energy and reducing reactant conditions in place of coal and natural gas while releasing only water vapour rather than climate-damaging CO_2. The benefits and technology to use hydrogen in place of coke and coal for steelmaking are understood, but there are stumbling blocks for making hydrogen that can make a difference in steelmaking. The major challenges that remain include making enough hydrogen, making it in a way that is environmentally superior, making it from renewables, making it at a price that produces steel that the market will buy, and creating the customer pull to invest in green hydrogen and green steel. To that end, according to Wolff, Nel has launched a target to reach a $1.50 per kilogram of hydrogen by 2025. According to the company, that target will enable the industry to compete with fossil-derived hydrogen and moves significantly towards cost parity with natural gas for DRI production. It is believed that DRI process customization for the use of hydrogen may bring the process the rest of the way to full parity with the natural gas approach.

Water electrolysis runs on electricity, and while electricity is by far the most important determinant of hydrogen cost using water electrolysis on a large scale, investments in reducing electrolyser CAPEX (capital expenditure) are also important especially considering intermittent renewable supplies.

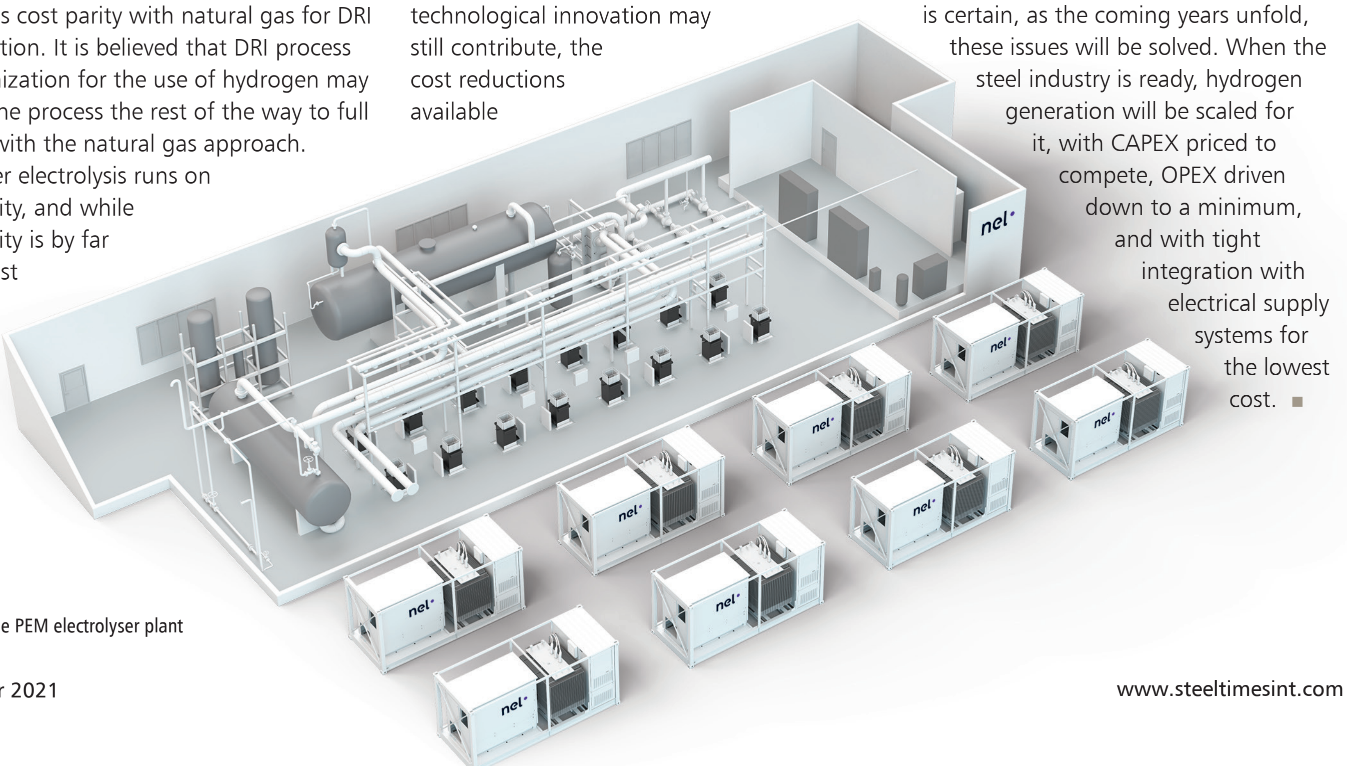
Nel is investing to reduce CAPEX in both alkaline and PEM (proton exchange membrane) electrolysers. While some techniques are common for both, such as larger volume manufacturing and advancements in automation, PEM is earlier in its technology life cycle and has opportunities for technology innovation around optimized materials, more efficient use of precious platinum group metal catalysts, and advanced component design.

Nel builds alkaline electrolysers in Norway, and builds PEM electrolysers in the United States. In Norway, the company is dramatically increasing its production capacity. Currently, it's at 40 megaWatts per year (input electrical power to electrolysis) and will increase shortly to 500 megaWatts per year with the completion of a new plant, and then to 2,000 megaWatts per year with subsequent expansions. In the US, the company is increasing its production for PEM systems to 50 megaWatts per year, with additional expansion planned as demand increases. Alkaline electrolysis is admittedly a more mature technology with most of the technological innovations already absorbed. Although some technological innovation may still contribute, the cost reductions available for alkaline electrolysis are primarily around volume purchasing and equipment simplification. By comparison, PEM technology is newer with room for significant technological innovation.

Electrolyser manufacturers often compare their capital cost analyses with traditional steam methane reforming to assess their timelines for expanded implementation. The process becomes competitive at a capital cost of $500 per kW and better at $300 per kW, which is the expected goal. According to Nel, technological improvements in PEM electrolysers will drive down the CAPEX for PEM electrolysis.

"For example, we are vastly increasing the size and capacity of our electrolyser cell stacks by a factor of 20, boosting the energy capability of a single stack to generate hydrogen reliably and efficiently," said Wolff. "The company is also reducing the CAPEX of its PEM electrolysis equipment by transitioning from largely handmade membrane electrode assemblies containing platinum group metals to volume production roll-to-roll manufacturing of membrane electrode assemblies."

Operational considerations will drive costs and create opportunities. The industry is working towards a better understanding about plant CAPEX and OPEX (operational expense) when intermittent operation is considered – as renewables are intermittent. The lingering questions are: When will hydrogen storage become more cost effective? What role will be played by alternative hydrogen outlets such as vehicle fuel, chemical intermediates, natural gas pipeline injection, and more? One thing is certain, as the coming years unfold, these issues will be solved. When the steel industry is ready, hydrogen generation will be scaled for it, with CAPEX priced to compete, OPEX driven down to a minimum, and with tight integration with electrical supply systems for the lowest cost. ■



Large scale PEM electrolyser plant