Fact sheet

Hydrogen (H2)-based ironmaking

The transition to a low-carbon world requires a transformation in the way we manufacture iron and steel. There is no single solution to CO_2-free steelmaking, and a broad portfolio of technological options is required, to be deployed alone, or in combination as local circumstances permit. This series of fact sheets describes and explores the status of a number of key technologies and issues.

What is hydrogen-based reduction?

Direct reduction of iron is the chemical removal (reduction) of oxygen from iron ore in its solid form.

The iron used in the steelmaking process is currently chemically reduced from iron ore through the use of fossil resources – natural gas or coal. This process is known as Direct Reduced Ironmaking (DRI).

Carbon combines with the oxygen in the iron ore, producing metallic iron and a carbon-rich process gas, according to the following simplified chemical reaction:

$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$

It is also possible to reduce iron ore using hydrogen instead of carbon; in this case the waste gas produced is water, as per the following reactions:

Fe2O3 + 3H2 -> 2Fe + 3H2O , FeO +H2 -> Fe + H2O

H_2 production and use now

Hydrogen can be extracted from hydrogen-bearing fuels, such as natural gas and biogas, and from water using electrolysis. The primary source of hydrogen production is currently natural gas, accounting for around three quarters of the annual global dedicated hydrogen production of around 70 million tonnes. This accounts for about 6% of global natural gas use.[1]

Currently, less than 0.1% of global dedicated hydrogen production comes from water electrolysis.

H_2 in the steel industry now

In natural gas-based DRI production, hydrogen does play a role in the reduction process, though this is in combination with carbon. Greenhouse gas (GHG) emissions from gas-based DRI production are lower than from the BF route, with every tonne of DRI produced leading to the emission of 1.5 tonnes of CO2. Pure hydrogen is not currently used in ironmaking applications.

Potential approaches

There are three main sources of hydrogen. 'Green' hydrogen is produced by combining renewable energy with electrolysis, 'blue' hydrogen is produced from fossil fuels in a facility equipped with carbon capture and storage (CCS), and 'grey' hydrogen comes from unabated fossil fuel.

In its 2020 technology roadmap, the International Energy Agency (IEA) suggests that under its 'Sustainable Development Scenario' (SDS) scenario, green hydrogen is introduced as a primary reducing agent at a commercial scale in the mid-2030s. Use expands to 12 Mt per year by 2050. While this represents a fast scale up and deployment of a new technology, the IEA's modelling suggests that by 2050 under 8% of total steel production will rely on electrolytic hydrogen as the primary reducing agent (or 14% of primary production).

State of on the ground development

Examples of blue hydrogen production include Shell's Quest project[2] and Air Products' Port Arthur facility.[3] The largest electrolyser in the world is currently a 10 megawatts (MW) unit located in Japan[4], capable of producing 1,200Nm^3 of hydrogen per hour. A plant with a capacity of 100 MW is to be built in the Port of Hamburg.[5]

Steel companies are currently looking at hydrogen use in a number of ways.

The first approach is to develop and deploy breakthrough hydrogen reduction technology, virtually eliminating direct GHG emissions from the ironmaking process. A number of steelmakers are taking this approach; key projects include Hybrit (SSAB/LKAB/Vattenfall) and ArcelorMittal's Hamburg

pilot project. The IEA views hydrogen reduction as being very important for net-zero emission, and at technology readiness level (TRL) 5, likely to be available from 2030.[6]

Another group of steelmakers are looking at the transitional use of hydrogen by blending it with fossil-based reductants, using it in conventional steelmaking processes (BF and DRI) to improve greenhouse gas efficiency. thyssenkrupp is testing the use of hydrogen in a blast furnace; this approach has also been studied in Japan as part of the COURSE50 project.[7] The approach is rated by IEA at TRL 7, ready for deployment in 2025.

Tenova, Salzgitter and thyssenkrupp have or are testing natural gas-based DRI with high levels of hydrogen blending (TRL 7, 2030). voestalpine's SuSteel project is looking to apply hydrogen plasma reduction to ironmaking, while the University of Utah is researching flash ironmaking technology (TRL 4). Hydrogen can also be used in ancillary processes, such a reheating furnace, as a substitute for natural gas.

Challenges

Scale up

Under the IEA's core Sustainable Development Scenario (SDS), electrolytic hydrogen as a primary reducing agent is introduced at commercial scale in the mid-2030s and expands to 12 Mt used in 2050. The IEA also expects that by 2050 the greatest demand for electrolytic hydrogen in steel is expected in India and China (just over 4.5 Mt of hydrogen in each) due to large production volumes and access to large amounts of low-cost renewable electricity.[8]

Around 70 Mt of dedicated hydrogen are produced today, 76% from natural gas and almost all the rest (23%) from coal. Less than 0.1% of global dedicated hydrogen production today comes from water electrolysis. If all current dedicated hydrogen production were produced through water electrolysis[1] (using water and electricity to create hydrogen), this would result in an annual electricity demand of 3,600 TWh – more than the annual electricity generation of the European Union.

Under IEA's SDS, global demand for hydrogen increases to 287Mt by 2050[9], which represents an increase of over 400% from 2020. This presents a massive scale up challenge.

Infrastructure

As a light and molecularly small gas hydrogen can be difficult to contain and specialised infrastructure may need to be developed to enable distribution at scale.

There are close to 5,000 km of hydrogen pipelines around the world today, compared with around 3 million km of natural gas transmission pipelines.[10] Existing high-pressure natural gas transmission pipes could be converted to deliver pure hydrogen in the future if they are no longer used for natural gas, but their suitability must be assessed on a case-by-case basis and will depend on the type of steel used in the pipeline and the purity of hydrogen being transported.[11] A further challenge is that three times more volume is needed to supply the same amount of energy as natural gas. Additional transmission and storage capacity across the network might therefore be required.[1]

Electrolysis requires water as well as electricity. Around 9 litres of water are needed to produce 1 kg H_2, producing 8 kg of oxygen as a co-product. This could be a challenge in water stressed areas.

Costs

The IEA found that innovative process routes (including CCS on the BF, smelt reduction and gas based-DRI) can be expected to cost 10-50% more than commercially available counterparts within a given regional context, noting this cost increase significantly exceeds profit margins from steelmaking today.[8] The IEA analysis found that the cost of producing hydrogen from renewable electricity could fall 30% by 2030 as a result of declining costs of renewables and the scaling up of hydrogen production.[1]

Safety issues

Like other energy carriers, hydrogen presents certain health and safety risks when used on a large scale. As a light gas of small molecules, hydrogen requires special equipment and procedures to handle it. Hydrogen is so small it can diffuse into some materials, including some types of iron and steel pipes, and increase their chance of failure. It also escapes more easily through sealings and connectors than larger molecules, such as natural gas.[1]

Hydrogen can also lead to embrittlement and cracking in steel pipes and vessels. Austenitic stainless steels do not suffer from hydrogen embrittlement.

Steelmakers are already developing and deploying Process Safety Management systems to manage the risk associated with loss of containment of hazardous materials, toxic or flammable. Risk assessments and associated controls will need to be updated to incorporate risks associated with hydrogen use when it is used.

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[2] https://sequestration.mit.edu/tools/projects/quest.html
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[8] Iron and Steel Technology Roadmap, IEA, 2020
[9] https://www.iea.org/data-and-statistics/charts/selected-decarbonisation-indicators-by-scenario-in-2050
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[11] https://www.nrel.gov/hydrogen/infrastructure-cdps-all.html