Fact sheet

Electrolysis in ironmaking

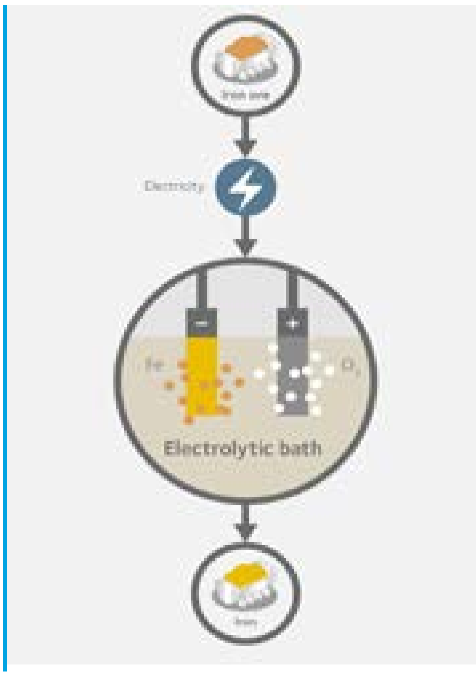
The transition to a low-carbon world requires a transformation in the way we manufacture iron and steel. There is no single solution to CO_2-free steelmaking, and a broad portfolio of technological options is required, to be deployed alone, or in combination as local circumstances permit. This series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

What is electrolysis?

Electrolysis is a technique that uses direct electric current to separate some chemical compounds into their constituent parts.

Electricity is applied to an anode and a cathode, which are immersed in the chemical to be electrolysed.

Electrolysis of water (H_2O) produces hydrogen and oxygen, whereas electrolysis of aluminium oxide (Al_2O_3) produces metallic aluminium and oxygen.



Siderwin concept, Climate Action Report, May 2019, ArcelorMittal

Why consider electrolysis in ironmaking?

There are two potential ways to separate metallic iron from the oxygen to which it is bonded in iron ore. These are through the use of chemical reductants such as hydrogen or carbon, or through the use of electro-chemical processes that use electrical energy to reduce iron ore.

In electrolysis, iron ore is dissolved in a solvent of silicon dioxide and calcium oxide at 1,600°C, and an electric current passed through it. Negatively-charged oxygen ions migrate to the positively charged anode, and the oxygen bubbles off. Positively-charged iron ions migrate to the negatively-charged cathode where they are reduced to elemental iron. If the electricity used is carbon-free, then iron is produced without emissions of CO_2.

Electrolysis of iron ore has been demonstrated at the laboratory scale, producing metallic iron and oxygen as a co-product.

Current status

The EU ULCOS project examined the prospects for electrolysis based ironmaking through their ULCOTWIN initiative.

- The Siderwin project, being led by ArcelorMittal, is looking at using low temperature electrolysis using a water-based electrolyte. The project has been taken to TRL4, and ArcelorMittal, surrounded by 11 additional innovative European partners, aims to develop a 3 metre-long new experimental pilot to validate the technology at TRL 6. The ULCWIN pilot plant used to validate the feasibility of the technology at TRL 4 has produced 4kg iron samples.

- Research at MIT led to founding Boston Metal, which commissioned its first prototype high temperature (1,500°C) molten salt-based cell in 2014 and has produced a total of more than 1 tonne of metal. The company is now aiming to construct a pilot scale plant.

Opportunities and challenges

Scale up

Globally in 2020, 1,864 Mt of steel was produced, with a typical blast furnace capable of making somewhere in the order of 2.5 Mt of iron in a year.

To date, batches of iron measured in kilogrammes have been manufactured using electrolysis, so an upscaling in volume of around 8 orders of magnitude would be required if electrolysis is to play a meaningful role.

The IEA's iron and steel roadmap noted 'direct electrification of steelmaking through electrolysis is not included in the Sustainable Development Scenario due to its comparatively low TRL. However, with accelerated progress on innovation, it could play a role in sustainable steelmaking in the longer term.'

Under the IEA's illustrative 'Faster Innovation Case', a scenario aimed at exploring the feasibility of bringing forward net-zero emissions for the energy system as a whole to 2050 is foreseen by accelerating work on clean energy technology innovation electrolysis, which plays a more meaningful role. IEA modelling suggesting that under these extreme conditions 100 Mt of iron ore electrolysis could conceivably be in operation by 2050. The IEA notes that there is scant precedent for the very rapid pace of innovation required in the Faster Innovation Case.

Energy availability

Since electrolysis produces no CO_2, it could theoretically be zero-carbon, but only if the electricity needed to power the process is generated without causing emissions, and that electrode consumption does not lead to CO_2 emissions.

A significant increase in low-carbon electricity generation capacity would be required to install electrolysis-based ironmaking at scale.

Boston Metals has set a target of 4MWh tonne of steel. If this were to be achieved, and the IEA's extreme 100 Mt example came to pass, this would need to be supported by 46GW of low-carbon generational capacity, which would be the equivalent of 5,500 of the worlds most powerful offshore wind turbines, or 28 1.6GW nuclear reactors.

Metallurgy

Unlike iron produced using conventional ironmaking techniques, electrolysed iron will be chemically pure, being formed of practically 100% Fe. Blast furnace iron (hot metal) is typically up to 5% carbon and contains a number of impurities (typically 0.6 to 0.8 percent silicon, 0.03 percent sulphur, 0.7 to 0.8 percent manganese, and 0.15 percent phosphorus) that must be refined during primary and secondary steelmaking to a level suitable for the final grade.

Typical ranges of DRI chemistry are 90–94% total iron, 83–89% metallic iron, 6.5–9% iron oxide, 0.8–2.5% carbon, 2.8–6% gangue, 0.005–0.09% phosphorus, and 0.001–0.03% sulphur. Gangue needs to be removed in the EAF or converter units.

Being pure, electrolysed iron represents a 'blank cavass', and alloying elements (including carbon) will need to be added to it to achieve the desired properties. This could be an advantage with very precise control of final steel chemistry being possible.

Electrodes

In 2018, Alcoa announced a joint venture with Rio Tinto called ELYSIS to scale up and commercialise a revolutionary aluminium smelting technology innovation by Alcoa that emits oxygen and eliminates greenhouse gases, this technology features the use of an inert anode. However aluminium electrolysis takes place at a significantly lower temperature than molten salt iron electrolysis.

Several engineering problems still need to be solved before iron electrolysis becomes economically viable. These include the development of a cheap, carbon-free inert anode that is resistant to the corrosive conditions in molten oxide electrolysis.

Flexibility

Like an EAF, but unlike a blast furnace, electrolysis-based production can be more easily scaled up and down to reflect the availability of renewable energy (for example solar and wind) and electricity prices.

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[1] Siderwin, targeting radically new steel production without CO2 emissions (arcelormittal.com)
[2] https://www.newscientist.com/article/dn9878-electrolysis-may-one-day-provide-green-iron/#ixzz6ltDO8Hqo
[3] Home | Siderwin (siderwin-spire.eu)
[4] Boston Metal | A world with no pollution from metals production
[5] FT Live "Hard to abate industries – decarbonising Steel-making", 26/04/2021
[6] Losses of up to 6% will occur in high voltage transmission, depending on distance. Lost In Transmission: How Much Electricity Disappears Between A Power Plant And Your Plug? |Inside Energy
[7] World's Most Powerful Offshore Wind Platform: Haliade-X | GE Renewable Energy
[8] Hinkley Point C Nuclear Power Station - Power Technology | Energy News and Market Analysis (power-technology.com)
[9] Alcoa -- ELYSIS
[10] Electrolysis of Iron Ores: Most Efficient Technologies for Greenhouse Emissions Abatement | SpringerLink