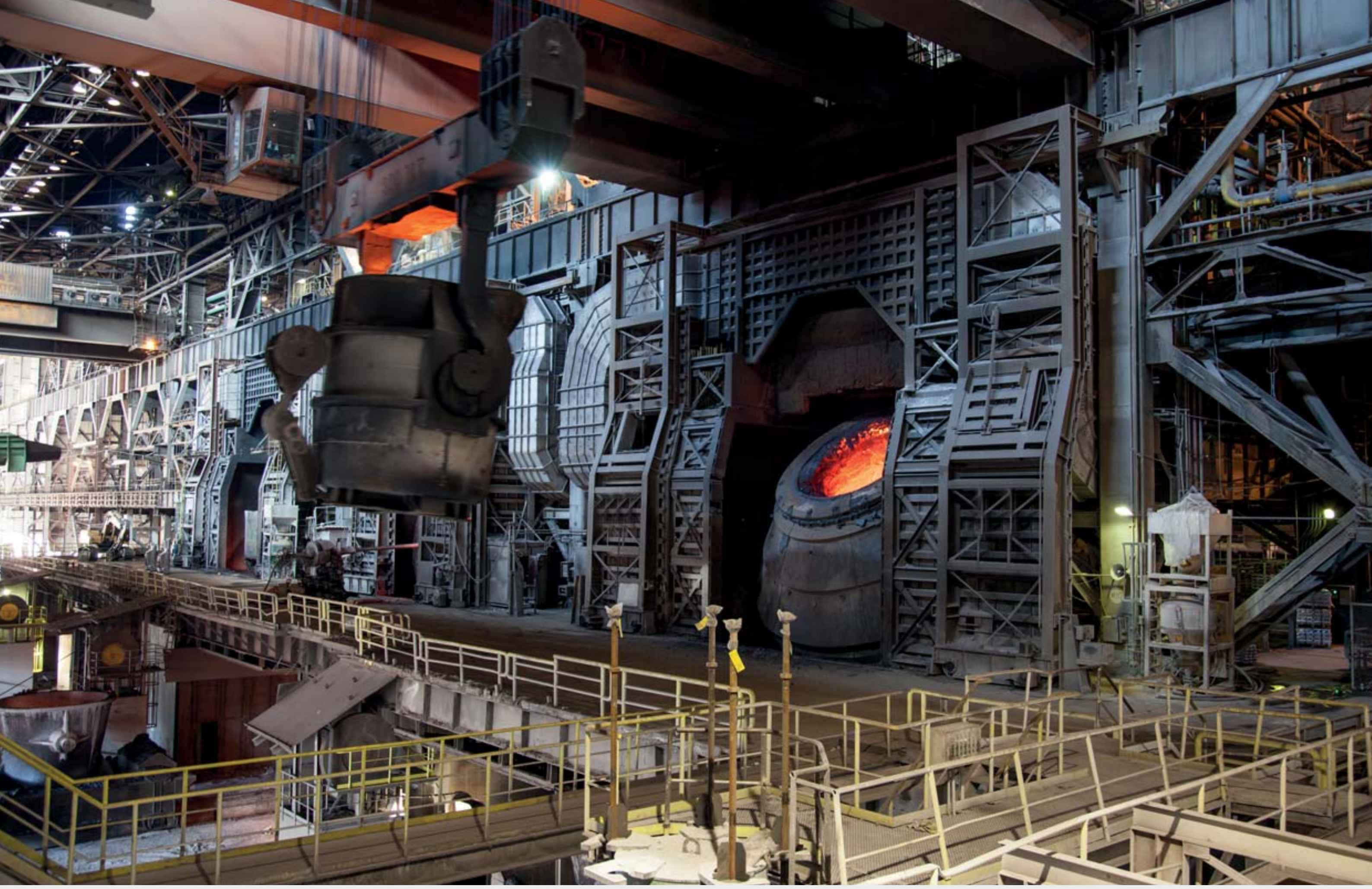

Green steel - the questions are not 'why?' and 'if?', but 'when?' and 'how?'

Green steel is not a choice, it is the only way forward. However, there are so many decarbonisation pathways open to the iron and steel sector that finding the right solution can be challenging. Many pilots are underway and their lessons will become lighthouses to help operating companies navigate their journey to net-zero.

The questions around green steel are not 'if?' and 'why?'. Rather the questions are 'how?', 'where?' and 'when?'. This article lays out some of the decarbonisation pathways and provides case studies of pilot projects to enable deeper research into the deployment of decarbonisation options to engage in the green steel revolution.

Stephen B. Harrison

Green steel - the question is not 'if?', but 'how?'

Steel is the backbone of every industrialized nation. It forms the skeleton of skyscrapers and is the main material used to build ships, buses, cars, trains, and trucks. It is also used to build electricity pylons for the grid and wind turbines that make renewable power. The energy transition cannot take place without steel.

On the other hand, per tonne of product, steel is one of the most carbon-intensive materials used in construction. The chances of finding a cost-effective alternative to steel with a low CO_2 intensity and similar mechanical properties are close to zero. So, the case for steel is clear. The future of iron and steelmaking can therefore be nothing other than green.

Flue gas flaring or power and heat recovery

Iron and steelmaking generate many thousands of tonnes of carbon dioxide (CO_2) annually. The emissions predominantly come from blast furnace gas (BFG) and basic oxygen furnace gas (BOFG). These flue gases contain carbon monoxide (CO), hydrogen, and methane. Methane is a potent greenhouse gas and CO is poisonous.

To avoid CO and CH_4 emissions, BFG and BOFG can be flared to convert these gases to CO_2 and water vapour. In some facilities, BFG and BOFG are utilized by feeding them to a gas engine which generates heat and power for the facility. In this case, the exhaust from the gas engine will be rich in CO_2 and water vapour, but the heat and power generation will avoid the use of some of the fossil fuel.

CO_2 capture using modern solvents

Many iron and steel producers are piloting processes for decarbonisation with emerging

Steel is the backbone of every industrialized nation. The energy transition cannot take place without it.

technology providers. For example, ArcelorMittal is using the patented DMX™ solvent-based CO_2 capture technology in the 3D Project, or DMX Demonstration Dunrkirk. The Project will capture CO_2 from blast furnace flue gases. CO_2 is produced when coke is used to reduce iron ore to iron.

Decarbonisation pathway	Application in iron and steelmaking	CO_2 emissions avoidance route
Replacement of blast furnace with DRI using blue hydrogen	Ironmaking	CO_2 capture during hydrogen production
Replacement of blast furnace with DRI using green hydrogen	Ironmaking	Renewable or nuclear power for water electrolysis to hydrogen
Substitution of fossil coke / coal in the existing blast furnace with biocarbon	Ironmaking	Sustainable biogenic CO_2 emissions*
Increased use of electric arc furnaces	Steelmaking, scrap re-processing	Renewable or nuclear power for the electric arc furnace
Plasma decomposition of CO_2 to syngas	Iron and steelmaking	Renewable or nuclear power for the electrical plasma
Reheating using electricity, blue or green hydrogen	Steel processing	Displacement of fossil fuel in steel reheating furnace
Fermentation of BFG, BOFG to ethanol and then synthetic fuels production	Iron and steelmaking	Avoidance of CO_2 emissions from flue gas combustion*, substitution of fossil fuel by ethanol-derived fuels
BFG, BOFG combustion for heat and power	Iron and steelmaking	Avoidance of CO_2 emissions from fossil fuel combustion for heat and power*
BFG, BOFG conversion to hydrogen using Water Gas Shift	Iron and steelmaking	Avoidance of CO_2 emissions from fossil fuel use in hydrogen production*
Iron oxide chemical looping BFG, BOFG flue gas conversion to hydrogen	Iron and steelmaking	Avoidance of CO_2 emissions from fossil fuel use in hydrogen production*

*CO_2 emissions can be further reduced if CO_2 from these processes is captured.

The DMX™ process and its unique solvent were innovated by IFPEN and will be commercialized by Axens. The unique aspect of this solvent-based CO_2 capture technology is that a CO_2-rich phase of the DMX™ solvent separates from a CO_2-lean phase prior to regeneration. Only this CO_2-rich phase needs to be regenerated.

Stripping CO_2 out of solvents in CO_2 capture processes is highly energy-intensive and is the main operating cost of CO_2 capture for solvent-based CO_2 capture systems. Since only a portion of the DMX™ solvent is required to be regenerated, a reduction in energy consumption is possible when compared to traditional solvents such as diethanolamine (DEA) or monoethanolamine (MEA).

In the future, CO_2 from the 3D Project will be sequestered in the proposed European Dunkirk-North Sea Cluster CCS scheme. Total is leading the development of the offshore CO_2 storage facility. CO_2 will either be transferred to the offshore storage location by ship as liquid CO_2, or by pipeline as a compressed or supercritical gas.

Flue gas to fuel jet aircraft

At their Ghent blast furnace, ArcelorMittal will run a demonstration project using the LanzaTech fermentation process. This process utilizes raw flue gases which are rich in CO to produce ethanol in a bioreactor. Ethanol can be used for many chemical and energy applications. For example, it is blended with gasoline at up to 10% in Europe and up to 15% in the USA. In China, 85% ethanol is blended with gasoline in some locations. The project has been referred to as Steelanol and also uses the name Carbalyst®.

LanzaTech's process was demonstrated at pilot-scale in 2008 using flue gases from the BlueScope Steel mill in Glenbrook, NZ. Since then, LanzaTech has successfully deployed its technology at two 300-tonne per annum demonstration facilities at Baosteel Shanghai and Shougang Steel Caofeidian in China. These LanzaTech fermenters are fed with a range of iron and steelmaking off-gases including BOFG, BFG, and coke oven gas (COG).

Alternatively, ethanol can be converted to synthetic aviation fuel (SAF) using the ethanol to jet (ETJ) process, which is also referred to as Alcohol to Jet or ATJ. LanzaTech's sister company LanazaJet has developed a proprietary ETJ process that maximises the yield of aviation kerosene in the various dehydrogenation and oligomerisation reactions that convert the ethanol to ethylene and then to SAF.

Tata Steel in the UK will also deploy the LanzaTech and LanzaJet processes to capture iron and

Raw flue gases that are rich in CO can be utilized to produce ethanol in a bioreactor. Ethanol can be used for many chemical and energy applications.

steelmaking flue gases from their Port Talbot facility. The project, known as DRAGON, will also use the Hummingbird® catalyst from Technip Energies (T.EN). This is a highly effective catalyst to dehydrate ethanol to ethylene.

The ethylene is then oligomerized to form paraffinic hydrocarbons of between 8 and 16 carbon atoms in length. These are then blended with other aromatics to obtain the required JET specification for aviation fuel. The aromatics are required to achieve the relevant distillation curve and ensure the fuel vaporizes appropriately in the jet engine burner.

Direct and indirect electrification

Electrification is also a viable decarbonisation pathway for iron and steel processing with many deployments being planned. As an example, ArcelorMittal will invest €67 million in a new electric arc furnace for their Belval site in Luxembourg.

Electric arc furnaces can be powered by renewable electricity from wind, solar and

Electric arc furnaces reduce scope 1 and scope 2 CO_2 emissions, thereby significantly reducing the CO_2 intensity of steelmaking, in addition to introducing an element of circularity through scrap re-processing.

hydro schemes. They can be fed with recycled scrap steel which is less energy- and CO_2-intensive than making fresh steel in a blast furnace. Electric arc furnaces therefore reduce scope 1 and scope 2 CO_2 emissions, thereby significantly reducing the CO_2 intensity of steelmaking, in addition to introducing an element of circularity through scrap re-processing.

The use of green hydrogen for the Direct Reduction of Iron (DRI) is an indirect method of electrification. Traditional blast furnaces use coal or coke to rip oxygen out of the iron ore through chemical reduction. An alternative to the use of solid coal or coke is to use natural gas or hydrogen as the reducing agent, as is done in MIDREX® plants.

Green hydrogen is produced from the electrolysis of water using renewable electrical power. CO_2 emissions are avoided through the electrification of the reducing agent production. For the iron maker, it is an indirect form of electrification.

Germany's thyssenkrupp will implement DRI at their Duisburg facility. Green hydrogen is proposed to be produced locally using wind power from a power purchase agreement. The green electrons will be transported to an electrolyzer scheme through the German power grid.

Biocarbon and biogenic CO_2

Biocarbon, produced from gasification or pyrolysis of wood and other biomass is also receiving attention as a substitute for coal or coke. Pulverized coal injection (PCI) can be used in some blast furnaces for iron ore reduction. Others rely on coke derived from coal for the same purpose.

Switching to biocarbon does not reduce the amount of CO_2 that is produced during the conversion of the iron oxide ore to iron, but since the trees removed CO_2 from the atmosphere during their growth, the biogenic CO_2 produced from biocarbon is regarded as carbon-neutral. It also avoids the use of fossil fuels.

ArcelorMittal Dofasco in Canada is proposing to pilot such a process and has signed a Memorandum of Understanding under which they will purchase biocarbon produced at CHAR's cutting-edge facility in Thorold, Ontario starting in 2023. CHAR's proprietary high-temperature pyrolysis cracking process transforms wood waste into renewable natural gas and biocarbon.

The biggest question for green steel is how to decarbonise

Perhaps more than any other hard-to-abate sector, there is a wide range of decarbonisation routes for iron and steelmaking. The decarbonisation imperative and motivation to go green are clear. The questions related to decarbonisation are not "why?" and "if?". The questions are "where?", "when?", and "how?".

About the author

Stephen B. Harrison is the founder and managing director of sbh4 GmbH. His work focuses on industrial decarbonisation and greenhouse gas emissions control. With a background in industry, including 27 years at BOC Gases, The BOC Group and Linde Gas, Stephen has intimate knowledge of gases used in iron and steelmaking. He is also an expert in hydrogen, ammonia, and carbon dioxide from commercial, technical, operational and safety perspectives.