CO₂ emissions in the steel industry vary depending on the ironmaking and steelmaking process route. The most common route is the integrated steelmaking process that uses the blast furnace (BF) for ironmaking and the basic oxygen furnace (BOF) for steelmaking (Figure 1). Approximately 70 per cent of global steel production relies on the BF/BOF route. Iron ore is used as the primary iron source, and metallurgical coke is used for the reduction of iron ore in the BF. The two other main routes for steel production involve an electric arc furnace (EAF) with scrap steel, or direct reduced iron (DRI) as an iron source. Approximately 30 per cent of global steel is produced in an EAF. Typically, 50 to 100 per cent of the feed for an EAF contains recycled steel scrap, with virgin iron units (DRI, or hot briquetted iron (HBI)) added to dilute scrap residuals or replace purchased scrap. Significant amounts of electricity are required to operate an EAF, however the direct CO₂ emissions are typically lower for the EAF route.

A summary of the CO₂ emissions for the three steelmaking process routes is shown in Figure 2. The DRI-EAF route assumes 100 per cent DRI feed to an EAF, and the scrap-EAF route assumes 100 per cent scrap feed to an EAF. Typical EAFs, which use a portion of both virgin iron units and scrap, will have emission values somewhere between the 100 per cent DRI and 100 per cent scrap-based routes.

There are several recent developments that aim to reduce the environmental footprint of the steel industry. Many emission reduction technologies and process routes fall into either the short- or long-term time horizon.

Emission reduction technologies that can be implemented today include (1) transition from a coal based integrated BF route, to a DRI or scrap based EAF route, or (2) applying incremental CO₂ reduction technologies to the integrated BF route. From Figure 2 above, it is apparent that emissions from the EAF steelmaking route, particularly when scrap is used, are lower than the BF/BOF route. To move towards greener steelmaking, a global transition to the EAF route could significantly reduce CO₂ emissions in the iron and steel industry.

There are however, some limitations to the EAF route. For EAF steelmaking to be a viable alternative to the BF/BOF route, low carbon electricity, and high-grade iron or available scrap is necessary. Generally, the availability of renewable power is increasing, and the scrap market in China is expected to increase, which makes the substitution of some BOFs with EAFs a likely reality. The transition to EAF steelmaking however, is not expected to be the complete solution to net zero carbon steelmaking.

Since 70 per cent of steel is currently produced using the BF/BOF route, applying incremental modifications and improvements to the existing blast furnace route will reduce the emissions per tonne of steel produced. Improvements to the BF/BOF route include technologies which make use of electrical energy, such as hot blast superheating, top gas recycling, stove or coke making process improvements, natural gas injection to the blast furnace to partially off-set coke requirements, or the use of alternative fuels such as biomass. Significant research and development effort is being applied in this area because it avoids the capital expenditure associated with implementing a completely new process route. A combination of incremental reduction technologies can assist the iron and steel industry in meeting 2030 emission reduction goals.

Long term emission reduction strategies include the adoption of breakthrough low emission technologies which completely transform the industry. These breakthrough technologies include hydrogen-based steelmaking, smelting reduction technologies, molten oxide electrolysis, electrowinning of iron ore, or end of pipe technologies.

Hydrogen technologies are considered to have significant potential to assist the iron and steel industry in achieving net zero emissions. Replacing carbon with hydrogen as a reducing agent generates water as a by-product instead of CO₂. There are two methods of hydrogen usage, (1) hydrogen injection into the BF to reduce the requirement of coal/coke, and (2) hydrogen to produce Hydrogen-DRI as an alternative to Natural Gas-DRI in EAF steelmaking. An obstacle with hydrogen usage is the renewable power...
resources and renewable hydrogen infrastructure which come at a significant cost. It is estimated that in order to completely replace carbon with hydrogen and produce the 1.8 billion tonnes of crude steel generated via all process routes in 2018, 64 million tonnes per annum of hydrogen is required, and 4.150 TWh/years of green electricity is needed to generate this amount of hydrogen.

Molten oxide electrolysis (MOE) and electrowinning of iron ore are two pilot-stage projects that are focused on totally new process routes and have the potential to completely transform and nearly decarburise the steel industry. Both of these process routes are in the early research and development phase and require significant scale-up to meet the demand of the steel industry. Furthermore, large amounts of electrical energy are required, therefore renewable power is necessary to ensure net zero emissions from these technologies.

Carbon capture storage and utilisation (CCS&U) could also play a role in moving towards low emission steel production. CCS&U processes capture CO₂ from waste streams and reuse it as a feedstock for the generation of various chemical products, avoiding the use of coal or natural gas feedstocks. Captured CO₂ from iron and steel waste streams could be used as-is to enhance oil recovery in wells or can be converted to higher value products such as bioethanol, biomethanol, or polymers. Currently, full-scale CCS&U is still in development, and the required CO₂ infrastructure does not exist, however CCU&S is expected to play a large role in a net zero industry post 2030. The iron and steel industry is putting significant investment into the research and development of technologies which will reduce the carbon footprint. Short-term solutions, such as incremental blast furnace improvements, or the transition to EAF steelmaking can help reduce the per tonne emissions of steel production, however, if a large reduction in CO₂ emissions is to be made, advancements in new alternative processes such as using hydrogen as a reductant, or green smelting reduction technologies are required to decarbonise the industry (Figure 3). Furthermore, government initiatives to support green energy and phase out fossil industries are crucial to advance these breakthrough technologies and make them both a sustainable and cost-effective alternative to the existing process routes.

References
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This is a summary of the article that originally appeared in the March 2021 edition of Iron and Steel Technology magazine, published by AIST https://www.aist.org