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Discussion-Opinion-Editorial

Part 1: Greening Steelmaking: All Round Progress and Adoption Made so Far - Technology and Progress

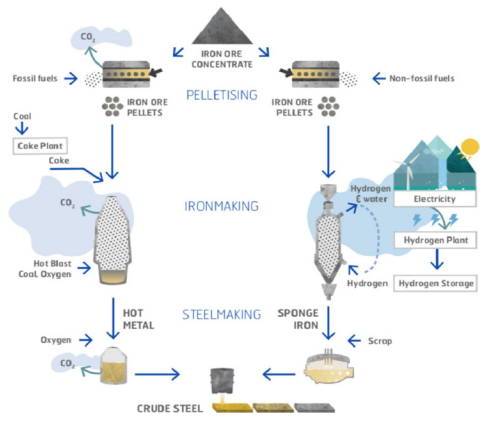
Jayanta Bhattacharya

Editor-in-Chief

Abstract

Around 75% of steel is still largely made in coal-fired blast furnaces, which pump large amounts of carbon dioxide into the atmosphere. A significant proportion of global steel production is currently based on the conventional Blast Furnace-Basic Oxygen Furnace (BF-BOF) which contributed 3 Gt of CO_2 emissions in 2019. Under real process conditions, depending on furnace and feedstock, the carbon requirement is in the best practice cases today around 400-450 kg per metric tonne of pig iron. The global average is about 500 kg per tonne of pig iron. Hydrogen as a low-carbon clean energy source is experiencing a global resurgence and has been recognized as an alternative energy carrier that can help bring the world to a carbon neutral future. However, getting to scale is one of the main challenges limiting the growth of the hydrogen economy. In particular, the high cost of transporting green hydrogen is bottlenecking the international trading and wider adoption of hydrogen for global carbon natural objectives. In order to explore incentives for the global hydrogen economy and develop new pathways towards the carbon neutral future, the concept of hydrogen credit is proposed and a framework of trading hydrogen credits similar to carbon credits in the international market is established.

Keywords: *Benefits, Green Hydrogen, Hydrogen, Incentives, Steel Making, Tax Credits*



Graphical Abstract: Iron and steelmaking. Traditional BF-BOF route (left) and hydrogen-based direct reduction (right)[1].

1. Introduction

As governments and industries around the world look to reduce carbon emissions to reach ambitious net-zero targets, steel is in the spotlight. Around 75% of steel is still largely made in coal-fired blast furnaces, which pump large amounts of carbon dioxide into the atmosphere. Huge amounts of energy are also needed to heat the furnaces to above 1,000 C. Overall, steel production accounts for around 8% of global emissions. Steel stands as a not so reputable leader in emission (Figure 1).

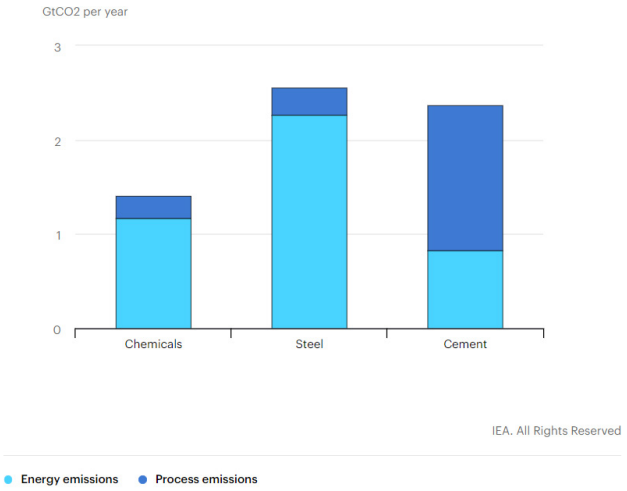


Figure 1. The emission comparison.

Green steel production is the process of making steel with a reduced environmental impact, and it uses a combination of technologies and methods. A significant proportion of global steel production is currently based on the conventional Blast Furnace-Basic Oxygen Furnace (BF-BOF) which contributed 3 Gt of CO_2 emissions in 2019. Since fossil fuels, mainly in form of coal and coke, are used in conventional steelmaking in considerable quantities, shifting to non-fossil fuels is an important step for decarbonization. This can be achieved through various means, such as reducing the use of carbon-based reducing agents and fuels in pelletising, moving from blast furnace process route to electric arc furnaces fed with steel scrap and direct reduced iron and powered by renewable energy, converting from fossil-based fuels to hydrogen or electricity in downstream processing (Figure 2)[1,2]. Some of the methods, currently being pursued, include:

a. **Renewable Energy**
Using renewable energy sources like solar, wind, and hydropower to power production equipment and furnaces.

b. **Green Hydrogen**
Using green hydrogen instead of natural gas in the direct reduced iron process to reduce carbon emissions.

c. **Scrap Steel Recycling**
Using scrap steel as a raw material to reduce the need for primary resources.

d. **Carbon Capture and Storage**
Capturing and storing remaining carbon dioxide emissions instead of releasing them into the atmosphere.

Clean Technologies
Using cleaner and more efficient technologies, such as electric furnaces for melting.

e. **Waste Minimization**
Minimizing waste through efficient production methods and recycling by-products.

f. **3MDIMET+® Technology**
A single-stage kiln process that requires less energy and capital than existing production technologies.

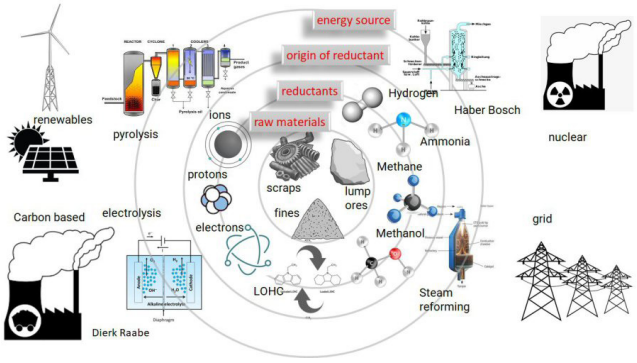


Figure 2. Some of the methods of greening steel industry, currently being pursued.

The strategy for low carbon steel production varies by region, depending on local capacities and constraints. For example, countries with fossil fuel resources may be better suited to blue steel production, while countries with limited fossil fuel access and abundant water resources may be better suited to green steel production. Greening steel production is important for several reasons, including[2,3]:

I. Sustainability: Green steel production reduces the environmental impact of steel production and helps to make it more sustainable. This includes reducing carbon emissions, reducing the use of non-renewable energy sources, and minimizing waste.

II. Climate change mitigation: Steel production is a major contributor to greenhouse gas emissions, and green steel production helps to mitigate the effects of climate change by reducing emissions and increasing energy efficiency.

III. Economic benefits: Green steel production can create new jobs and stimulate economic growth, as well as improve the competitiveness of the steel industry. In fact green steel can revive the steel industry particularly in the USA and the Europe as these will be more publicly acceptable.
IV. Consumer demand: There is growing demand from consumers for environmentally friendly products, and green steel production helps to meet this demand.
V. Legal requirements: Many countries have set targets and standards for reducing greenhouse gas emissions, and green steel production helps to meet these requirements.
VI. Strategic need: As fossil fuel resource is concentrated in very few countries, who control the prices and availability, green steel production will reduce dependence on the conventional supply routes.
VII. Cost reduction in the supply chain: Take the case of green hydrogen. If used in steel making (that we will discuss in the latter part of this discussion), it will reduce the transportation cost of the conventional fuel and the logistical requirements (Figure 3).

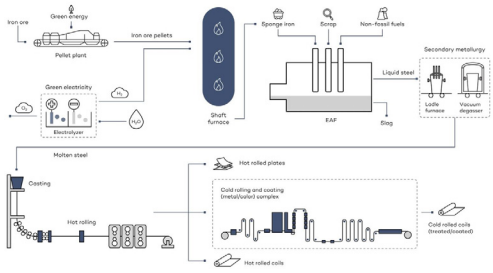


Figure 3. Various green steel feasible prospects.

2. Blast Furnace for Green Steel Making

The blast furnace process is the standard method and backbone of global raw iron (pig iron) production. In the blast furnace process, pig iron, *i.e.* a eutectic Fe alloy with up to 4.3 weight % carbon and many impurities inherited from the coke and from the ore is produced from iron oxides by smelting reduction. The reduction is mainly carried out by carbon monoxide obtained through the Boudouard reaction and to a small extent by hydrogen. The reducing agents are formed from hydrocarbons such as coke, oil, crude tar, natural gas, *etc.* by gasification with oxygen. The gasification process also provides the energy needed for the process. Compared to combustion, where only heat and CO_2 are formed, in the blast furnace carbon is gasified into carbon monoxide, which does most of the reduction work. CO_2 is formed as a product of the redox reactions that take place (Figure 4).

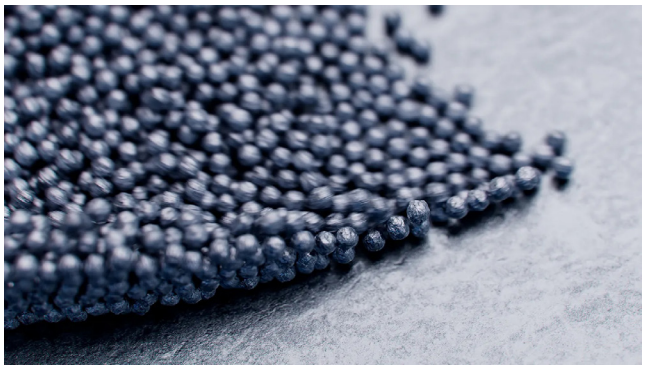


Figure 4. Green steel (In a direct reduction process, will produce high-quality green iron. By replacing fossil fuels with green hydrogen, we effectively slash CO_2 emissions.)

A thermodynamically and stoichiometrically idealized blast furnace process would require around 370 kg of carbon per metric tonne of pig iron produced, a value that is close to the thermodynamic limit of the redox reaction. Under real process conditions, depending on furnace and feedstock, the carbon requirement is in the best practice cases today around 400-450 kg per metric tonne of pig iron. The global average is about 500 kg per tonne of pig iron[3].

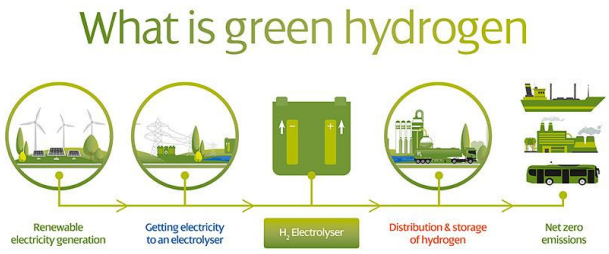
A further significant reduction in carbon consumption is not possible under the given prerequisites and conditions. This also means that a limit has been reached for a further reduction in process-related CO_2 emissions. A further CO_2 reduction in pig iron production can only be achieved by substituting conventional iron carriers with pre-reduced materials such as the so called low reduced iron for instance from direct reduction[3].

3. Green Hydrogen as a Technology for Greening Steel

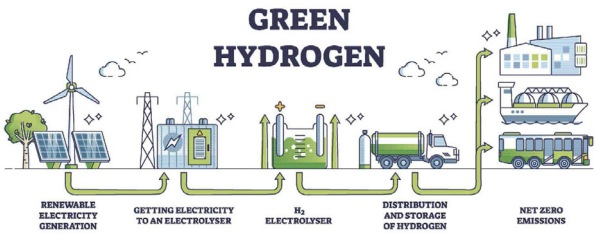
Green hydrogen is a carbon-neutral fuel that is produced by splitting water molecules into hydrogen and oxygen

using renewable energy like wind or solar power (Figure 5). It has several advantages, including:

1. **Environmentally Friendly**
   Green hydrogen is a sustainable and environmentally friendly way to produce energy, and it produces significantly fewer greenhouse gases than other types of hydrogen.
2. **Energy Independence**
   Green hydrogen can help reduce dependence on fossil fuels and provide a reliable source of energy.
3. **Local Production**
   Green hydrogen can be produced locally, which can reduce the need for costly imports.
4. **Energy Storage**
   Compressed hydrogen tanks can store energy for long periods of time and are lighter than lithium-ion batteries.
5. **Revenue for Local Communities**
   Green hydrogen produced from waste biomass can provide an additional revenue stream for local communities.



(a)



(b)

Figure 5. Green hydrogen.

In the world, there are already several projects Hybrit and H_2 Greensteel, for example that aim to replace fossil fuels with green hydrogen, while in the United States, Boston metal, a company that emerged from the Massachusetts Institute of Technology (MIT), is developing direct electrolysis from iron ore, a process similar to that currently used for aluminum[4,5]. In both cases, the electricity used would be from renewable sources, ensuring sustainability and no emissions during the process. Green hydrogen is achieved through a process of electrolysis powered by renewable energies such as wind or solar. Electrolysis involves using an electrical current to break down the water molecule into oxygen and hydrogen by electrodes[5].

4. How Hydrogen by Electrolysis Can Qualify as Green

To qualify as green hydrogen two requirements have to be fulfilled:

1. Water has to be electrolyzed to produce hydrogen.
2. The energy of the electrolysis has to be from the renewable source. For example, in 1.00 Mw electrolyser plant nearly about 1.40 Mwh of power is required, including losses and ancillary power. So if such a plant runs for 24 hours, 33.6 or 34.00 Mw will be the nominal power requirement. Now suppose the plant has a solar plant connected either physically or by a grid, and the solar plant produces 35 Mw power per day. This power is supplied to the grid. If the power from the grid is taken for the electrolyser plant at the rate of 1.4 Mwh for 24 hours, the whole process is dubbed as green (Figure 6).

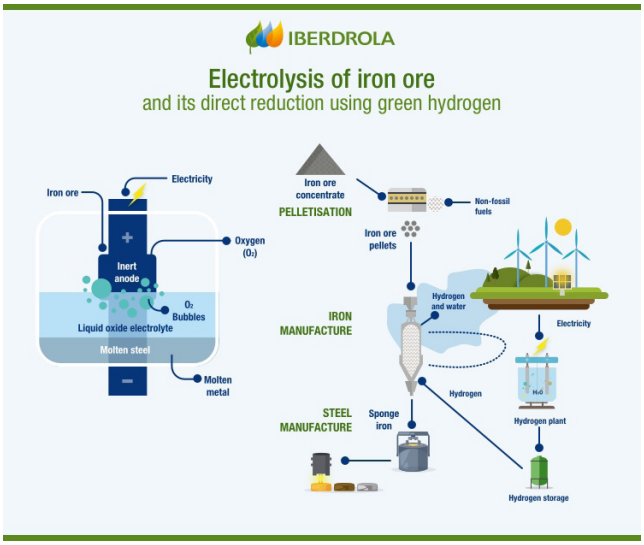


Figure 6. Green hydrogen in direct reduction[5].

5. Green Hydrogen Credit Subsidized Renewable Energy-Hydrogen Business Models

The adoption of low emission H_2 as a clean industrial feedstock is still in its infancy. The trend indicates that the availability of green H_2 will remain limited in the short term and uncertain in the long term, hindering investments in H_2 infrastructures and end use applications. The main barriers to large-scale H_2 utilization lie in the high production costs, a relatively small market size, and inadequate infrastructure. Therefore, innovative financial mechanisms and business models are essential to promote the development of the H_2 industry, especially for green H_2 which generates zero emissions during production.

A pre-feasibility study of the production cost of hydrogen-based steel would be 20–30 % higher compared to today's production of conventional steel from BF-BOF processes, with the key determinants being the price of fossil-free electricity, the price of carbon emissions, and the price of the coke used in conventional steel making.

Incentives and financial support are needed to expedite the development of the H_2 industry, especially considering the current high cost of green H_2 production. These incentives and financial support mechanisms include providing direct subsidies or grants to companies involved in green H_2 production, implementing investment tax credits for businesses, and offering low-interest loans or loan guarantees to companies. Meanwhile, financial and CO_2 reduction are closely interconnected in the context of sustainable practices, *via* implementing carbon emission markets, improving environmental awareness of consumers, and ensuring regulatory compliance in environmental matters. Entities that align financial decisions with sustainability goals can achieve both economic benefits and CO_2 emission reduction.

The current high costs associated with green H_2 hinder its adoption as a clean energy source, calling for financial support and incentives for H_2 investors, manufacturers, users, *etc*. The H_2 credit framework, leveraging the emission reduction potential of H_2 and coupled with the carbon credit market, is designed to stimulate the global uptake of green H_2 (Figure 7).

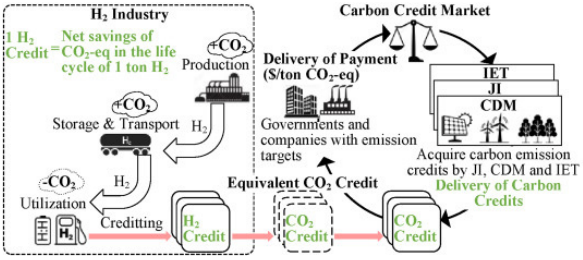


Figure 7. A green hydrogen credit framework for international green hydrogen trading[6,7,8].

6. Tax Benefits: Hydrogen Tax Credit Norms and Guidance

The U.S. Department of Energy Hydrogen and Fuel Cell Technologies office in the Office of Energy Efficiency and Renewable Energy offers information about federal and state financial incentives for hydrogen fuel cell projects[7,8].

6.1. Federal Incentives

The Inflation Reduction Act of 2022 (IRA) includes clean energy tax credits and other provisions that would increase domestic renewable energy production. The IRA's clean energy incentives include many provisions for clean hydrogen and fuel cell technologies, either extending many existing federal tax credits, increasing existing federal tax credits, or creating new federal tax credits, including the following programs[7].

1. Advanced Energy Project Credit (Extends IRC Code Section 48C)
2. Alternative Fuel Refueling Property Credit (Extends 30C)
3. Carbon Capture and Sequestration Tax Credit (Extends 45Q)
4. Clean Hydrogen Production Tax Credit (New, 45V)
5. Clean Vehicle Credit (New, 30D)
6. Elective Payment for Energy Property
7. Energy Credit (Extends 48)
8. Energy Storage Credit (New, 48)
9. Qualified Commercial Clean Vehicles Credit (New, 45W)

6.2. Potential Types of Implementing Guidance will includeTreasury regulations

I. Notices, Revenue Procedures, Revenue Rulings, and Announcements (sometimes referred to as

sub-regulatory guidance or Internal Revenue Bulletin guidance).

II. IRS forms, instructions, and publications.

III. FAQs, news releases, and fact sheets.

IV. This web page will be updated as appropriate as the implementation process proceeds toward completion and issuance of final rules and regulations.

The US Treasury decision to require electricity generation from intermittent renewable power projects to be matched eventually with hydrogen output hour-by-hour will be challenging to make work to the extent the electrolyzers require around the clock operation to be economic[6,7]. The Inflation Reduction Act authorized a tax credit of up to $3 a kilogram for producing clean hydrogen. A hydrogen producer must show its life cycle greenhouse gas emissions to produce hydrogen are less than 0.45 kilograms of CO_2 equivalent per kilogram of hydrogen to qualify for the maximum credit. It can be claimed on clean hydrogen produced and sold or used during the 10 years after a plant is originally placed in service. Projects must be under construction by the end of 2032 to qualify. Hydrogen producers have a choice of a one-time investment tax credit for 30% of the project cost instead. The treasury imposed three other requirements in addition to a low-emission production process for hydrogen to qualify as clean. Hydrogen producers will be treated for purposes of tracking emissions as using electricity from power plants from which they buy Renewable Energy Certificates (RECs) or similar "Energy Attribute Certificates" (EACs). Any such power plant cannot be more than 36 months older than the hydrogen plant. It must be in the same region as the hydrogen plant. The electricity used must match the hydrogen output hour by hour starting in 2028. Annual matching is permitted until then. The tax credit amounts vary depending on the greenhouse gases emitted to produce a kilogram of hydrogen. The greenhouse gases are converted into CO_2-equivalent emissions. To claim credits at the full rate of $3 a kilogram, the production process must lead to less than 0.45 kilograms of CO_2 equivalent emissions per kilogram of hydrogen. This part of the discussion is a work in progress. Many things will be clarified in the days to come[8,9].

7. Green Steel Prospects

A leader in green steel, the European steel sector is going through the transition to green steelmaking, with several multi-billion dollar investment projects already announced and more than 50 million tonnes of new steelmaking capacity expected to come online in 2025-2027, according to estimates. Major flat steel suppliers are already offering their own green steel brands with lower carbon footprints – including XCarb, Arvzero, SSAB Zero, Bluemint, Greentec, but there is currently no common standard for green steel – although one group defines European green steel as "steel produced with Scope 1,2 & 3 emissions at a maximum of 0.8 tonne CO2 per tonne of steel."Here's some information about Scope 1, 2, and 3 emissions in the steel industry:

Scope 1 emissions

Companies can reduce these emissions through operational efficiency and predictive maintenance.

Scope 2 emissions

Companies can reduce these emissions through power purchase agreements and a mix of renewable energy sources.

Scope 3 emissions

These emissions include upstream emissions (procurement of raw materials, shipping) and downstream emissions (transport, warehouse management, scrap processing). Some companies don't include Scope 3 emissions in their goals and targets.

Technologies to reduce emissions

Technologies such as DRI-EAFs, iron ore electrolysis, and using iron ore fines to make DRI in a fluidized bed furnace could help reduce emissions.

Steel industry's commitment

The steel industry supports the aims of the Paris Agreement and is committed to reducing its footprint. Market participants said there was a lack of projects across Europe requiring green steel and that demand from the key consumer – the automotive industry – has recently been slowing, in line with the general downturn in steel sales."Our customers say they love green steel but they can't pay more because they are fighting for

their survival," one participant said. "We can't reverse the decarbonization and reduced-CO2 steel is coming – it's just the matter of time. But in a recession, it just becomes a secondary [issue] for a buyer," he added.

The EU's Common Border Adjustment Mechanism (CBAM) regulation is one of the major drivers behind the decarbonization of steelmaking in the EU and globally. It's a tool intended by the EU to put a fair price on the carbon emitted during the production of carbon-intensive goods that enter the trading bloc. Steel production in the EU is steadily going down and the future outlook of local and global market growth is not rosy. In such a situation there is nervousness in the forward investment in green steel as market weariness grows. For green steel to advance, a universal mechanism like CBAM is necessary for adoption under the current situation..

(Part-1 is complete, In the part -2 we will discuss about the green steel production using green hydrogen. We will talk about the three leaders in the run for green hydrogen steel making in the world. It will also cover the safety and water aspects as well.)

N.B. For all round adoption of green hydrogen, an external consultant team is an absolute necessary for those entering the field. Zelence Industries Private Limited helps put together a team of external consultants to help plants transition to green hydrogen adoption.

Disclaimer: The author does not recommend any technology or organization for green hydrogen adoption; he merely suggests pointers for action. Users discretion is necessary.

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