ACHIEVING NET-ZERO STEEL

BY

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Steel is the foundation of our buildings, vehicles, and industries, with its rates of production and consumption seen as markers for a nation's development. Today, it is the world's most used metal and most recycled material.

Global steel production has more than tripled over the past 50 years. Despite its current dominance, China could be preparing to scale back domestic steel production to curb overproduction risks and promote high quality development of the industry to reach carbon neutrality by 2060.

Bold cross-sector collaboration and ambition from stakeholders across the steel value chain is critical if the industry is to decarbonise by 2050. Clear and supportive policies must be implemented by governments globally.

The corporate demand signals for low emission and net zero steel are rapidly growing. Businesses recognise that the carbon emissions associated with the steel that they buy and use needs to be addressed to meet their own targets. The current market for "green" steel is underdeveloped and the definition unclear. A host of barriers face the steel industry on the path to net zero, there is no simple solution.

To achieve net zero steel, industry thinking must focus on key criteria needed to facilitate rapid and deep decarbonisation and ensure current carbon reduction opportunities and nascent technology can provide the solution.

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Current Steel Production and CO_2 emissions

Steel and cement production account for just over 50 per cent of all industrial emissions. The need for continuous high-temperature heat to produce these vital materials requires huge amounts of energy, much of which is still dependent on fossil fuels. The chemical processes involved in producing them are themselves a major source of emissions.

The world uses a huge volume of steel – 1.9 gigatons (Gt = billion tonnes) of it in 2020. All kinds of goods and infrastructure including wind turbines, buildings, EVs, tin cans, appliances (fridges, ac units, cookers...), even solar panels – are all made with steel.

To make that steel, (90% of all metal produced globally), 3.7 gigatonnes (Gt) of carbon dioxide (CO_2) was emitted into the atmosphere in 2020, 2.6 Gt in direct CO_2 emissions and a further 1.1 Gt of indirect CO_2 emissions, 7% of the world's total greenhouse gas emissions (GHGs) – not including other GHGs such as methane (CH_4), nitrous oxide (N_2O) and various other hydrofluorocarbons.

Demand for this globally traded material is on the rise as many countries continue to industrialize, particularly in Asia. The volume of steel used between now and 2050 is estimated to increase by more than a third. Without targeted measures to reduce demand for steel where possible, and an overhaul of the current production fleet, CO_2 emissions are projected to continue rising.

Steel Production (Mt)				
Rank	**Country**	**(2020)**	**(2021)**	**(% change)**
#1	China	**1,064.7**	**1,032.8**	**-3**
#2	India	**100.3**	**118.1**	**17.8**
#3	Japan	**83.2**	**96.3**	**15.8**
#4	Russia*	**72.7**	**86**	**18.3**
#5	United States	**71.6**	**76**	**6.1**
#6	South Korea	**67.1**	**70.6**	**5.2**
#7	Turkey	**35.8**	**40.4**	**12.7**
#8	Germany	**35.7**	**40.1**	**12.3**
#9	Brazil	**31.0**	**36**	**14.7**
#10	Iran*	**29.0**	**28.5**	**-1.8**

*Source: World Steel Association. *Estimates.*

Pledging Net Zero and how it differs from Carbon Neutral

> *"The number of countries announcing pledges to achieve net zero emissions over the coming decades continues to grow. But the pledges by governments to date – even if fully achieved – fall well short of what is required to bring global energy-related carbon dioxide emissions to net zero by 2050 and give the world an even chance of limiting the global temperature rise to 1.5 °C."* (IEA)

Major steel-producing countries, including China, Japan, the EU and now the US, have set ambitious targets to reach net-zero economies. Achieving them demands not just further material efficiency, greater recycling of scrap steel and continued process efficiency; it will take a shift to radically different zero-emissions primary (ore-based) steelmaking. A range of solutions – from replacing coal with green hydrogen as a reducing agent, to reducing single-use CO_2 through carbon capture, utilisation, and storage (CCUS), and eventually direct iron electrolysis – are being trialled or are approaching technological readiness. These solutions are being championed by several early-adoption steel producers.

When industry speaks about becoming Carbon Neutral, it means they will take steps to remove the equivalent amount of CO_2 to that which is emitted through activities across their supply chains, by emissions reduction and investing in offset programmes that absorb residual CO_2. To achieve Net Zero means to go beyond the removal of just carbon emissions, it refers to removal of all GHGs being emitted into the atmosphere, such as methane (CH_4), nitrous oxide (N_2O) and other hydrofluorocarbons.

Challenging Proposition by 2050

The steel sector is currently the largest industrial consumer of coal, which provides around 75% of its energy demand. Action to reach net zero by 2050, a demanding timeframe, is taxing the greatest minds and producers in the steel industry as change needs to happen on a global scale, requires more action and greater ambition in policy setting and regulation by world governments, the development of a viable market for "green" steel as well as huge investment by and cross-sector collaboration throughout the steel value chain.

Long investment cycles of 10 to 15 years, multibillion financing needs, and limited supplier capacities make this issue even more relevant, and significant lead times are inevitable in addressing the decarbonisation challenge.

Despite welcome commitments to Industrial Decarbonisation and Net Zero Strategies, comprehensive plans by governments, including targeted and more accessible investment to support fuel switching, transformation of whole production processes and large-scale deployment of new and more reliable technologies, are needed to create a global business environment conducive to attracting the significant investment into steel production that will result in much lower CO_2 emissions.

Up to 90% of downstream Scope 3 emissions attributable to mining iron ore, arise from the subsequent smelting and refining of mined products to make steel. Iron ore miners can also meet their decarbonisation targets by helping steelmakers reduce their GHG emissions, not only addressing Scope 1 and 2 GHG emissions arising from their businesses, but these downstream Scope 3 emissions as well.

Achieving Net Zero Steel – Three Key areas of Industry Consensus

i) Demand Management

Sustaining projected demand growth whilst reducing emissions poses an immense challenge. If the steel sector is to reduce the emissions from steelmaking to net zero by 2050, demand management is key; demand for steel needs to reduce through more efficient design and use of steel or use of more sustainable, alternative materials.

In their *"Action Plan for Carbon Dioxide Peaking before 2030"*, the NDRC (National Development Reform Commission of The People's Republic of China), state that:

> *"We will deepen supply-side structural reform in the steel industry, rigorously execute production capacity replacement, strictly prohibit additional production capacity, push for the optimization of existing capacity, and retire outdated capacity. We will promote mergers and reorganization of steel enterprises across regions and ownership types, to make the industry more concentrated. We will optimize the layout of productive forces and continue to push down steel production capacity".*

Government policy in China is currently focused on the elimination of the oldest most polluting plants and on reducing Sulphur dioxide (SO_2), and nitrogen oxide (NO), emissions to cut particulate pollution, necessary action to achieve net zero. Whilst this will inevitably reduce CO_2 emissions, given that China accounts for more than half the world steel production, (and produces 90% of its steel in blast oxygen furnaces), a clear strategy to decarbonise Chinese steel production, driving forward cost-effective energy efficiency measures and maximising the efficient use of resources, is essential.

Whilst India is the second largest producer of steel by country, steel consumption per capita is still very low at around 64kg per year, consistent with its low GDP per capita. This is only 27% of the world average and an indication of the potentially large growth in steel consumption required to raise GDP and continue to develop the economy and support growth and higher levels of industrialisation. The National Steel Policy of 2017 (NSP 2017) set a target to more than double capacity by 2030, with further growth expected in the long term such that India's steel demand could grow by a factor of five by 2050 with continued growth beyond.

Demand management also includes material efficiency, more efficient use of steel in product design, development and circularity. Extending the life of products (especially buildings, which account for 40% of steel usage) through improved design and taxation targeted at whole-life embodied carbon. This and greater recycling of scrap steel will help unlock emissions reductions potential estimated at over 20%, despite increased output.

Steel is one of the most highly recycled materials in use today. Iron ore is the source of around 70% of the metallic raw material inputs to steelmaking globally, the rest comes from recycled steel scrap. Steel production from scrap requires only ~13% of the energy of that produced from iron ore – mainly electricity, which can be sourced from renewables, rather than coal for production from iron ore. Despite high recycling rates (around 80-90% globally), the availability of scrap cannot fulfil the sector's raw material input requirements alone, as there is insufficient supply vs demand for new steel.

ii) Energy Efficiency

New and more efficient steelmaking processes are critical, but there is no one right answer. Hydrogen, carbon capture, use and storage (CCUS), direct electrification and bioenergy all constitute potential avenues for achieving deep emission reductions in steelmaking, with multiple new process designs being explored and trialled today.

The carbon emissions trajectory from the steel industry will be strongly driven by the changing mix of different production processes. Around 70% of steel is currently produced via the Blast Furnace – Basic Oxygen Furnace (BF-BOF) process, a method which uses coal as both a feedstock and energy source. BF-BOF furnaces produce emissions of about 2.3 tonnes of CO_2 per tonne of steel produced, DRI with gas as the input produces about 1.1 tonnes, while the EAF process (based on scrap or direct reduced iron) produces about 0.4 tonnes, and less still if the electricity used comes from renewable sources.

Replacing coal or natural gas as the fuel in a blast furnace is a significant technical challenge. It can be done by using any of the aforementioned avenues, hydrogen or biofuels or by direct electrolysis of the iron ore. These emissions could be cut further by incorporating carbon capture utilisation and storage (CCUS) technology, where geographically and geologically feasible.

To achieve climate goals in the steel sector, the age of existing infrastructure cannot be ignored. Due to recent rapid growth in global crude steel production capacity, specifically in China and emerging economies, the resulting global blast furnace fleet is relatively young. Early replacement or retirement will be necessary to decarbonise the steel sector in line with climate pledges and necessary interim targets, sacrificing remaining useful life for more efficient and latest steel making technology. If operated until the end of their typical lifetime under current conditions, even with innovative CCUS emissions reduction retrofits, cumulative CO_2 emissions from this existing global blast furnace fleet would leave no room for capacity additions anticipated over the coming decades.

Improving the energy performance of existing equipment by itself will not be sufficient for the longer-term transition. The energy intensity of state-of-the-art blast furnaces is already approaching the practical minimum energy requirement. For inefficient and emissions intensive equipment the gap between current energy performance and best practice is sufficiently large that production cost savings are already an incentive to replace the least efficient process units. Improvements in operational efficiency, including enhanced process control and predictive maintenance strategies, together with the implementation of best available technologies may reduce cumulative emissions by up to 20%.

To meet global energy and climate goals, emissions from the steel industry must fall by at least 50% by 2050, with continuing declines towards zero emissions being pursued thereafter. EU legislation indicates a 35% interim reduction by 2035. While more efficient use of materials helps to lower overall levels of demand (relative to IEA baseline projections), the average direct CO_2 emission intensity of steel production must decline by 60% or more by 2050.

iii) Developing the market for Green Steel

Given that steel is an internationally traded commodity, an uneven transition to net zero on a global scale may create competitiveness issues. An internationally coordinated carbon price coupled with the development of “green” steel standards and labels across the steel value chain, are thus essential to mitigate the risks of competition distortion.

A common definition for “green” steel is needed to enable the development of an international market. Regulation, such as the introduction of the European Union’s new Carbon Border Adjustment Mechanism (CBAM) will also require a common definition or different “green” steel categories to be defined. An industrywide rating system that is clear and easy to understand will help gain the trust of both customers and consumers. The reasoning behind it must be transparent and conform to GHG calculation protocols.

It is anticipated that technologies such as green-hydrogen DRI–EAF, will increase cost of production per metric ton of “green” steel, however, the resulting steel price increases in many consumer industries translate into relatively modest price increases for the end customer.

Initial demand for “green” steel over the next few years is difficult to calculate. The construction industry which consumes a large percentage of the steel production volume globally, will be driven by the need to reduce embodied carbon in infrastructure and buildings. The need for manufacturers to reduce carbon emissions in products will drive purchasing and this demand will continue to grow driven by the need to reduce scope 3 upstream emissions, carbon taxes and consumer energy prices.

Steel makers and product manufacturers can proactively target these potential markets for “green” steel with persuasive sales pitches emphasizing the environmental benefits and the premium nature of their products as demand for it grows, thus contributing indirectly to investment in and financing of the market transformation.

Once clearly defined, a policy commitment to 100% “green” steel in all publicly funded infrastructure and buildings by governments around the globe, will help to accelerate the development of the market for “green” steel. We are already seeing a commitment to tightening of regulations and border taxes with the introduction of the CBAM. Once this is fully up and running, with an adequate level of carbon tax, it will be an easy next step to ensure all government funded projects include specifications for “green” steel products. In addition, downstream steel-based goods sold will need to be subject to progressively tightening regulation on their levels of embedded energy intensity.

Larger manufacturing industry sectors, such as cars and shipbuilding, and the construction industry (in particular for steel reinforcement used in the construction of concrete assets), should define “green” steel commitments from today and at interim years to 2050 and beyond, as well as supporting the development of “green” steel design standards and their implementation.

Other Essential Drivers of Deep Decarbonisation

Attracting the Investment Needed

Significant investment is needed now and in the next decade to drive large-scale technology transformation in the decarbonisation timeframe required. Funding will be required to cover additional costs, including support for R&D, market creation for near-zero emission steelmaking technologies and support for demonstration projects.

Financial institutions and investors will be seeking sustainable investment schemes to guide finance towards emission reduction opportunities, and it is already clear that any new facilities proposing emissions-intensive technologies, will struggle to attract funding due to risk of becoming future stranded assets.

The finance community has indicated a clear readiness to support the transition of the steel industry. The investment needs are substantial. Transitioning the first plants to green steel in the 2020s, totalling 170 Mt of production capacity, will require $100 billion in investment. Leading lenders to the steel industry are already working together to support steel sector decarbonisation.

It is estimated that China's goal to become carbon neutral in 2060 will require $6.4 trillion of investment in new power generating capacity, before even considering investment specific to steelmaking. It is predicted this could lead to a major shift in manufacturing and commodity imports and relocation of plants closer to sources of renewable energy or where the proximity of potential storage for captured CO_2 is more feasible.

The actual roll-out of technologies between now and 2050 is hard to predict and will depend on the funding and success of R&D, access to affordable energy and materials inputs and infrastructure, policy stringency and character, and various other supporting conditions that enable globally competitive steelmaking.

The future cost impact of new technologies currently under development remains uncertain and there is value in steelmakers and potential investors exploring the sensitivity of technology outcomes to varying cost assumptions. This would help identify which conditions would facilitate one technology being more competitive than another. Energy prices will influence the cost of different production routes. There is significant volatility and regional variation in these such that the competitiveness of different technologies will vary by region according to the respective energy price context.

Country level analysis of investment needs indicates the need for major shifts in capital investment from existing producers (e.g., China, South Korea) to new facility sites in Africa and India. While the cost of "green" steel to end users is low, it is significant and risky for producers - key policies to drive this shift include a clear definition of "green" steel, green public and private procurement to reduce the risk of investment in low carbon technologies and to increase production and innovation in economies of scale.

Bilateral offtake agreements between green steel manufacturers and purchasers in the automotive and white goods industries can unlock investment in the first wave of commercial-scale green steel production plants. Combined with broader public commitments to greener supply chains from users down the construction value chain, this will help create a fast-growing premium market for 'green' steel.

To achieve net zero in the steel sector, any residual emissions that cannot be abated through technology developments must be counterbalanced by permanent removals. It is probable that the cost of purchasing or producing such removals will fall to steel producers themselves. These costs should therefore be factored into decision-making when considering which technologies to pursue and invest in on the path to net zero and the overall cost of transition.

Policy and Regulation

Steelmakers face mounting pressure from multiple stakeholders, including investors, activists, end users, and governments, to curb CO_2 emissions and take more urgent steps to ensure there is a chance of limiting the global temperature rise to 1.5 °C (At COP27 there seems to be more talk of a target of 2°C already).

Rather inconsistently across the globe, governments are adopting regulatory measures designed to incentivise high-emissions industries to act, including the steel industry. Europe is leading the way. The European Union's new Carbon Border Adjustment Mechanism (CBAM) is essentially a tariff imposed on steel imports on the basis of the amount of carbon embedded in them.

CBAM will require importers to report embedded emissions starting next year (2023) and will become fully operational in 2026. The mechanism aims to create a level playing field between EU producers and importers of steel from outside the bloc to prevent strategic carbon leakage (efforts to move production offshore in order to avoid EU climate costs or to replace EU products with more carbon-intensive imports).

The EU envisages the CBAM acting as an incentive for other parts of the world to ramp up their own carbon-pricing regimes.

Governments in the major producing countries will need to play a central role in the transition. Countries should develop transition plans – including national roadmaps – with explicit focus on the iron and steel sector, how to deal with existing assets and the adoption of robust policies to implement them. International co-operation will be essential to ensure a level playing field. The steel industry should engage with governments as they develop national roadmaps and policy design. Steel producers should be proactive with the performance improvement of existing plants, collect and share process data to support benchmarking efforts, and share technical expertise when proposing and undertaking R&D and demonstration projects.

The People's Republic of China, the worlds largest steel producer by far, has created a national carbon-pricing system that is expected to take steel emissions into account within the next few years, although currently there is still no specified date for commencement. The administration has required energy intensive industries to report their emissions since 2020 and has adopted an energy efficient programme for top performers.

Elsewhere globally, India's Perform, Achieve, Trade (PAT) Scheme encourages energy efficiency, the US has announced its intention to reduce its emissions by at least 50% by 2030 (compared with 2005 levels), on the way to net-zero emissions by 2050, and South Korea has had an effective emissions trading scheme (ETS) since 2015.

The Japanese government, in addition to improving the energy efficiency of its domestic steel sector, has collaborated with the Japanese Iron and Steel Federation on international technology transfer activities. Japan, currently the third largest producer of steel, has provided expertise and support to improve the energy efficiency of steel plants in India, other Asian countries and as far afield as the EU.

Policy, not just investment funding, must clearly dictate that no more BF-BOF plants can be constructed post 2030 (or even sooner – much like ICE vehicles). New facilities should be planned and regulated as near zero-emissions alternatives. This requires a multi-level policy commitment to transition to a net-zero GHG industry.

In addition to managing the emissions and energy efficiency, policy should be used to drive higher re-use and circularity. A much stronger network is needed in some regions to gather and sort recyclable scrap. Vehicles, buildings, and infrastructure need to be designed, initially with lower embodied carbon and with longer design life expectancy, but also to be disassembled at end of life in a way that allows high quality, low contamination recycling. This will require revised and stronger building codes covering design and construction, with minimum recycling levels embedded in policies to encourage material efficiency and the highest possible level and quality in recycling.

Starting the process of clean replacement now requires a fast and effective global innovation process to commercialise green H_2 direct reduced iron, which is underway in Europe and must be expanded swiftly to the main steel producing countries, particularly China and India, through regulation or the encouragement of global technology partnering between major producers and the value chain.

Taxation and Incentives

While it has rejoined the Paris Agreement and is aiming for net zero by 2050, The US is taking the approach that whilst some regional carbon-pricing systems exist in the US, federal carbon pricing is not proposed at present. National action will primarily focus on regulating emissions and product standards, green procurement, and tax incentives. It remains unclear whether this package will be sufficient for the EU to give US exports an exemption from the CBAM.

As previously noted, the fact that decarbonisation may significantly increase steel prices creates a potential competitiveness problem on a global commodity trade scale. This could be overcome by the imposition of a uniform carbon price or tax agreed per tCO_2e (equivalent) and applied on a globally coordinated basis – or at least between major producing regions. Currently, however, where carbon pricing exists there is huge price variability between countries, with many steel producing nations yet to develop a pricing market let alone impose or agree a carbon price on manufacturers and polluters.

Imposing product regulations which require major steel users (such as the automotive and construction industries) to use a rising percentage of low/zero-carbon steel, thus effectively imposing a carbon tax on steel use within an economy irrespective of the location of production, is another possible route to add momentum to industry.

Embracing Key Existing and Nascent Technologies

Over the short to medium term, technologies that are already mature or in early stages of adoption will play the greatest role in reducing emissions, albeit somewhat incrementally, whilst in the longer-term technologies that are currently in the demonstration or prototype phase will be required to achieve deeper reductions, particularly from primary steel production.

Excess Energy Recovery

The simplest form of action to reduce the average energy intensity of crude steel is to deploy waste heat recovery, where possible, in the steel making process to transform it into useful energy. Some of these technologies can directly reduce fuel inputs into the steel production, whilst others produce low-emissions electricity from waste heat rather than directly from fuel. This electricity could be used in the CO_2 capture and separation process, making it even more efficient.

Top-pressure recovery turbines (TRTs)

TRTs use the pressure and heat of the blast furnace gas for electricity generation and can yield around 30-60 kWh of electricity for each tonne of pig iron produced (depending whether wet or dry de-dusting of top gases is used), reducing the load on utilities and imports of power from the grid. Around 20% of blast furnaces globally are equipped with TRTs. Whilst the economics of application need review, based on the level and stability of grid electricity prices at each facility, it is anticipated that all existing blast furnaces will be retrofitted, and new ones integrate this equipment and technology by 2050.

Steel Scrap

There is significant untapped potential to use recycled scrap in some major producing countries, specifically India and China. Using EAFs to process scrap steel enables decarbonisation of the production of commodity-grade steel. To produce higher grades of steel, companies must use DRI-EAFs. In the EU, recycling levels are already high and the introduction of scrap to various stages in the primary steelmaking process is already commonplace as it reduces energy needs and also helps with temperature control. Therefore, increasing the share of scrap in primary routes could be an avenue to technology performance improvements and emissions reduction. Even so, at a global level, scrap will remain in short supply as new steel will be in high demand in emerging markets, where there is limited supply, and so cannot fully replace ironmaking.

Replacement of Upstream Plant Facilities

Another carbon reduction concept involves entirely replacing the upstream facilities, the blast furnaces and basic oxygen furnaces (BF-BOFs) of a traditional integrated steel producer with direct-reduced iron plant electric arc furnaces (DRI–EAFs). This is a capital-intensive option using proven technology. These furnaces run on natural gas with plans to replace them eventually by green hydrogen (H_2), dramatically reducing the plant’s carbon emissions. This technological improvement could reduce emissions by 30% to 55% compared with the BF-BOF production route.

Replacing natural gas will ultimately require access to significant volumes of green H_2. Supply networks are expanding for grey, brown, black and blue H_2 that make up over 90% of available hydrogen currently (grey, brown and black from various fossil fuels, blue from captured carbon). Green H_2 is created using renewable energy rather than fossil fuels. It is currently generated only on a small-scale and it is hoped that it can be economically produced at scale within the required timeframe.

Hydrogen (H_2) Powered DRI Plants

In October 2022 a major EU-based steel producer announced it would invest €2 billion to build a hydrogen-powered DRI plant for low-CO_2 steel. This will help it to accelerate the start of low-CO_2 steel production and make an important contribution to achieving national and European climate targets.

Powered by green H_2, a DRI plant would have a near zero emissions profile and the technology is available right now. As already stated, the distribution networks for H_2, especially green hydrogen, to steel making facilities globally need to expand to enable greater change at a faster pace.

Carbon Capture (Utilisation) and Storage – CCUS

CCUS technology is set to be a key pillar in achieving the transition to net zero steel. It is the only group of technologies that contributes both to reducing emissions in critical industrial sectors such as steel production directly, and to removing CO_2 to balance emissions that cannot be avoided – a balance that is at the heart of net-zero emission goals.

A cross-sectoral approach to supporting CCUS transport and storage infrastructure and hydrogen production will be critical. Recent industry analysis has identified that CCUS uptake needs to grow 120 times by 2050 for countries to achieve their net-zero commitments.

So far, the technology is not moving fast enough, as only a limited number of small capacity carbon capture or utilisation pilots are currently underway or in the planning phases. These feasibility and design studies are for new plants and to understand how carbon capture technology can be incorporated into existing steel plants.

CCUS technology could ultimately offer a way to produce low-carbon steel in existing blast furnace or basic oxygen furnace (BF–BOF) plants via carbon capture. Uses have been identified for captured CO_2, such as conversion to sustainable ethanol. Mitsubishi Heavy Industries Engineering's (MHIENG) Kansai Mitsubishi Carbon Dioxide Recovery Process (KM CDR Process) has been used to capture the CO_2, a process which utilises an advanced amine solvent, in conjunction with a line of proprietary equipment. MHIENG has been developing the technology with Kansai Electric Power since 1990, and it is currently used in 14 plants around the globe.

As CCUS technology matures, it is likely that the storage option from steelmaking will be more viable ultimately for the volumes needing capture. This still has challenges associated with the identification of specific geological formations that allow CO_2 to be pumped and retained underground as well as development and provision of an extensive network of carbon transportation and storage infrastructure.

Even when suitable land based and offshore geological locations are identified, gaining access to them may prove difficult due to public concern onshore and offshore accessibility. In 2021, the IEA examined CO_2 storage opportunities in three key regions and identified that:

- The **United States** is the leader in global CCUS deployment, home to more than 60% of current CCUS capacity and around 50% of capacity under development.
- **Europe** is progressing significant CCUS development in the North Sea and around CCUS hubs. In September 2020 the Norwegian government committed USD 1.8 billion to the Longship CCS project, which includes the “Northern Lights” CO_2 transport and storage hub, and the UK government has announced GBP 1 billion to establish CCUS in four industrial regions.
- In the **People’s Republic of China**, which accounts for around one-third of global emissions today, the 2060 carbon neutrality target announced in September 2020 is already providing a major push for CCUS.

Detailed geospatial analysis shows that around 70% of power and industrial emissions in China, Europe and the United States are within 100 km of potential storage. The proximity of storage to steelmakers, where feasible clustered around CCUS hubs with shared infrastructure, will be a crucial factor in reducing costs, decreasing infrastructure development times, and enabling rapid rollout of CCUS.

Opportunity is already being taken to develop technologies for re-use of captured CO_2 in the steelmaking process, as has already been developed for the concrete industry. Faster deployment is needed to meet CO_2 reduction targets.

Among the pre-commercial near-zero emission technologies, the innovative smelting reduction route with CCUS has the lowest overall production cost in most regions at current energy prices and estimated capital and fixed operating costs for when this technology reaches market introduction.

Direct Electrification - Electrolysis

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

In electrolysis, iron ore is dissolved in a solvent of silicon dioxide (SiO_2) and calcium oxide (CaO) 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.

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.

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.

Bioenergy

Bioresources such as biochar, biogas, and biomass have a limited but potentially valuable role to play in the steel sector's transition. The use of bioenergy coupled with CCUS could, in theory, generate negative emissions from steelmaking, but truly sustainable biomass is a limited resource. Substituting just 20% of steel energy production with charcoal biomass would, according to an assessment by Mighty Earth, result in use of almost 200 million hectares of forest land per year – a serious threat to forests that are today absorbing large amounts of carbon out of the atmosphere.

Since biomass is unlikely to be a feasible route on a large scale except in specific locations with large sustainable biomass resources, the most likely key drivers of the path to deep decarbonisation will be cost-effective investment in capturing carbon from BF-BOF furnaces; developing feasible captured CO_2 transportation and storage networks and the political acceptability and cost of the CO_2 transportation and storage; and ultimately the cost of renewable electricity to produce hydrogen via electrolysis.

There is unpredictability in the final trajectory that will **achieve net zero steel**. The cost of decarbonisation could be dramatically reduced or even eliminated by new and unanticipated technologies. We must push on with R&D and decarbonisation implementation, be bold and imagine a world where the entire steel industry is net-zero from end to end.

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