Decarbonising the Indian Steel Industry

Roadmap Towards a Green Steel Economy

Report / March 2023

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About RMI

RMI is an independent nonprofit organisation founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous and zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities and NGOs to identify and scale energy system interventions that reduce greenhouse gas emissions by at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing. RMI has been supporting India's mobility and energy transformation since 2016.

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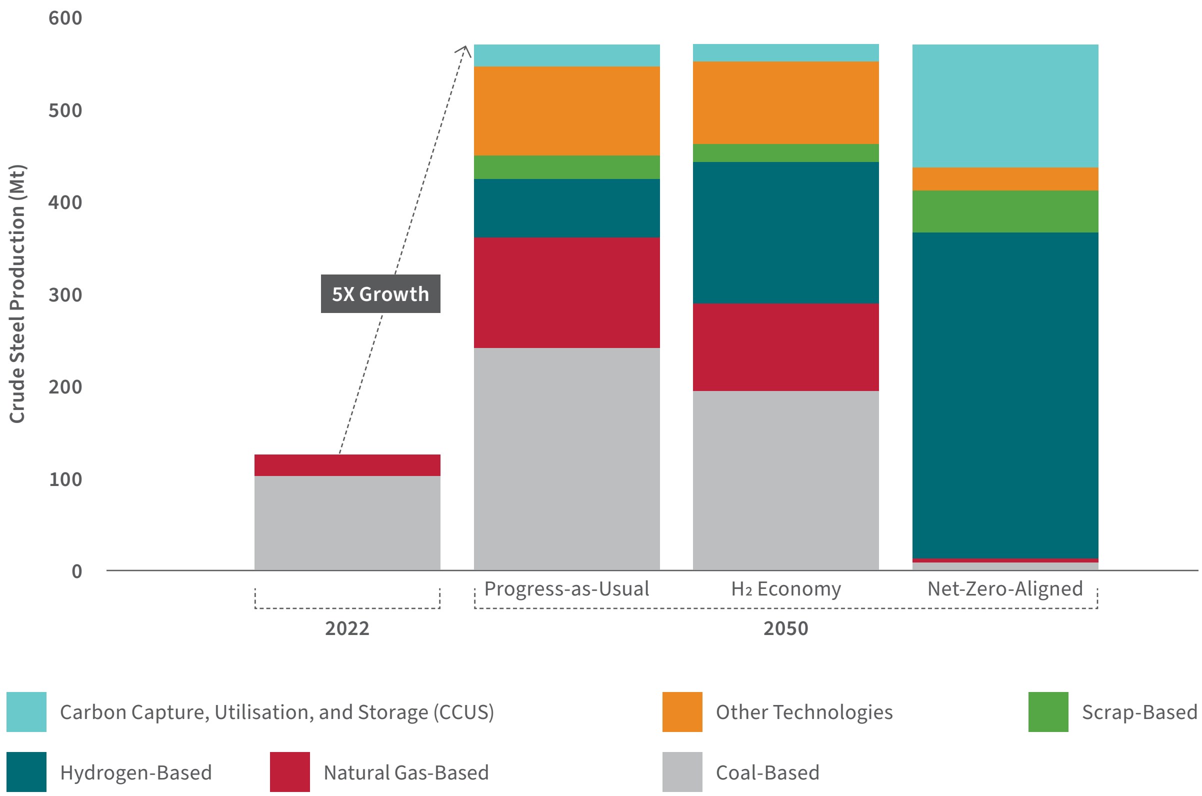
Executive Summary

The iron and steel sector has been critical to India's economic growth. This sector accounts for close to 23% of India's gross value addition as of 2022 but also contributes to around 34% of total industrial emissions (highest among all industrial sectors) as of 2016.[1,i] With greater economic growth and industrialisation, the importance and role of steel to support India's growth will compound. This necessitates the emergence of a decarbonised steel industry to ensure the success of India's economic ambitions and climate mitigation goals.

The analysis presented in the report indicates that India's total finished steel demand can increase by around 80% to 197 million tonnes (Mt) by 2030 and nearly 4.5 times to 527 Mt by 2050 from current levels (115 Mt in 2022) with per capita demand of steel increasing beyond 321 kg per person by 2050. Correspondingly, crude steel production is expected to reach 576 Mt by 2050 (see **Exhibit ES1**).

Exhibit ES1 **Decarbonisation Pathway Scenario Outlooks for the Steel Sector in India**



Source: RMI analysis

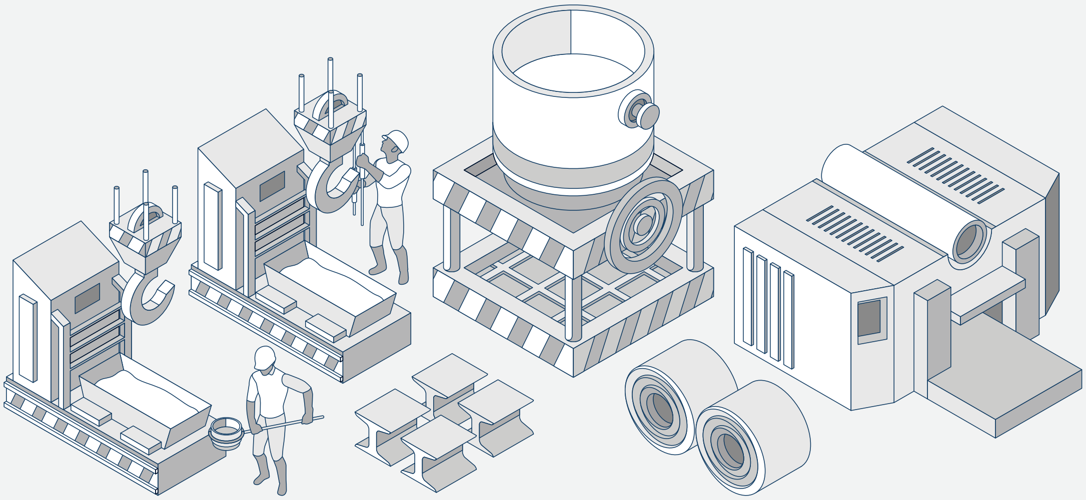
i Share of greenhouse gas emissions from the iron and steel industry across the manufacturing industries and construction categories in 2016, according to *Third Biennial Update Report* (BUR3), Ministry of Environment, Forest and Climate Change of India (MoEF&CC), 2021.

Given sunk investments in existing assets and the inertia against industrial transition, in a progress-as-usual (PAU) scenario, the sector would continue to be heavily fossil fuel dependent with increasing but limited penetration of cleaner options like green hydrogen (H_2)–based steel. Consequently, emissions also would increase 2.8 times, reaching almost 900 Mt CO_2 per year by mid-century, up from 320 Mt CO_2 in 2022.

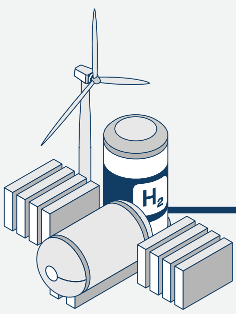
However, as the report also indicates, the sector could undergo a transformative shift to help move the needle towards a net-zero economy, depending on the emergence of a conducive policy and techno-commercial environment. In our most ambitious scenario, which follows India's net-zero-aligned targets, around 60% of steel produced would use the green H_2-based direct reduced iron (DRI) process, followed by 23% using fossil fuel–based carbon capture, utilisation, and storage (CCUS)-equipped production. Per the analysis, with growing steel demand, cumulative emissions from the steel sector are expected to be nearly 18.5 gigatonnes (Gt) CO_2. However, India can mitigate around 8 Gt CO_2 of emissions between 2022 and 2050 cumulatively. The emissions intensity of the sector would decline up to 0.4 t CO_2 per tonne of crude steel (tcs) by 2050, from 2.6 t CO_2/tcs currently.

This report identifies five key levers to decarbonise steel: use of green hydrogen for steel production, introduction of a greater share of renewable electricity in captive electricity consumption, CCUS to decarbonise existing carbon-intensive steel production processes, greater use of scrap to make steel, and increasing energy efficiency across steel production processes. As highlighted in **Exhibit ES1** (see previous page), the transition to green hydrogen–based steel and the introduction of CCUS are the most critical levers. But there is a wide gap in techno-economic feasibility between the conventional route and green H_2-based steel. An aggressive green H_2 price target coupled with relevant incentives and market creation mechanisms will be required to enable an effective cost-reduction pathway. Although it is promising, CCUS is yet to reach maturity and wider adoption. Multiple initiatives such as establishing the carbon market, building a policy ecosystem, promoting pilots and communicating guidelines for adoption will be essential. Using scrap for steelmaking can reduce the carbon intensity of steel, but the availability of scrap remains inadequate. Given these and other challenges discussed in this report, **Exhibit ES2** (see next page) distils specific recommendations with respect to encouraging each of the levers.

Exhibit ES2 Steps for Making Steel Decarbonisation Levers Viable in the Indian Economy

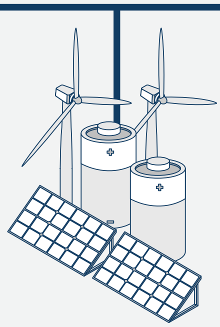


Key Levers to Decarbonise Steel Sector in India



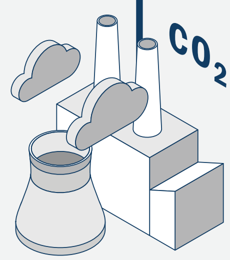
Promoting Hydrogen Adoption

- Waiving off state electricity charges to make renewable electricity affordable for green hydrogen production
- Supporting research and development to make hydrogen techno-economically feasible for adoption
- Aggressive target setting on green hydrogen price and providing policy pathways to accelerate price decline
- Focusing on domestic manufacturing of electrolysers and other advancement in infrastructure value chain
- Promoting pilots and clusters as demonstration projects to spearhead the adoption journey and build trust among stakeholders
- Facilitating green finance mechanisms such as green bonds, sustainability-linked bonds, concessional finance to support the investment needed for transition



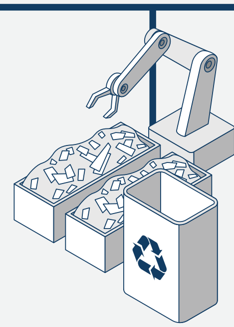
Adoption of Renewable Energy

- Promoting plant-level renewable purchase obligations mandating RE-based electricity adoption in steel industry
- Replacing fossil-fuel-based captive capacity with renewable energy captive power plants to support energy needs with green alternative
- Promoting R&D with respect to electricity/electrolysis-based steelmaking to electrify the complete process and ensuring that the electricity demand is met by RE



Promoting CCUS Technology Adoption

- Supporting R&D to make CCUS techno-economically attractive mitigation technology to be adopted with conventional steelmaking routes
- Undertaking government-led diligent exercise to identify CO_2 storage sites and quantifying the capacities
- Promoting pilots and clusters as demonstration projects to build trust among stakeholders
- Fast tracking development of carbon market in India to value carbon mitigation efforts and thus making tech routes like CCUS and H_2 economically attractive



Increasing Scrap Utilisation

- Expanding the scope of scrappage policy beyond automobile sector to quantify and channelise quantum of scrap availability in the country
- Increasingly formalise the scrap recycling sectors by streamlining collection, valuation, distribution, etc.

Improving Energy Efficiency

- Making PAT targets more stringent to direct steel makers to adopt more energy efficiency measures
- Informing guidelines for tech adoption in greenfield projects to ensure adoption of BAT technology routes
- Regular maintenance monitoring and evaluation to ensure high operational efficiency of plants

Source: RMI compilation

Roadmap for a Green Steel Economy

India recognises these challenges and has begun formulating policy frameworks to guide industrial decarbonisation. Recent policy advancements such as a commitment for INR 19,744 crore (US$2.4 billion) under the National Green Hydrogen Mission, which is supported by the National Green Hydrogen Policy, signal the development of an ecosystem that will help decarbonise the steel sector in the long term. But as this report shows, much more action is needed.

Based on analysis and stakeholder consultations, the report proposes a roadmap for making a low-carbon steel economy a reality in India with actionable steps relevant to stakeholders. The roadmap aims to achieve six key objectives:

1. **Establishing the definition and standards of green and low-carbon steel:** Key near-term actions include policy measures such as defining green/low-carbon steel and establishing standards for green products. This would provide clear benchmarking of emissions mitigation requirements for the sector.

2. **Advancing the uptake of alternative green energy sources such as green H_2 and renewable energy:** Policy initiatives could range from mandating renewable electricity and green H_2 usage to a near-term, government-led incentivising mechanism for green steel manufacturers.

3. **Announcing a green steel procurement policy and targets to encourage market creation and demand aggregation:** Revising and raising the ambition of the National Steel Policy with more focus on modern technologies and overlaps with other emerging industries, such as green H_2 products and CCUS, would send the right signals to steelmakers to kick-start deep decarbonisation.[ii] In the medium and long term, required actions range from mandating green steel procurement targets to creating a market for low-carbon steel and supporting that emerging market to fast-track the transition.

4. **Supporting R&D to advance breakthrough technologies and solutions like H_2 and CCUS:** The transition towards low-carbon steel is fundamentally dependent on breakthrough technologies like green hydrogen and CCUS, which need dedicated R&D support to scale and compete with conventional technologies. In the longer term, R&D funding can be channelled to focus on direct electrification of steelmaking routes such as electrolyser-based steelmaking.

5. **Promoting alternative emissions mitigation actions through pilots and clusters:** Proof of concept through pilots and clusters will be instrumental in making stakeholders believe in the viability of solutions being explored. Demonstrations will establish trust in the technology, drawing investment and policy support.

6. **Framing mechanisms and frameworks for financing the green steel transition:** Financing is a critical element in making the steel sector transition work. Increasing access to sustainable finance, such as green bonds or sustainability bonds, and access to concessional finance could move green investments in the near term.

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ii The National Steel Policy 2017, which is administered by the Ministry of Steel, is an effort to steer the industry to achieve its full potential and enhance steel production with a focus on high-end, value-added steel while being globally competitive.

Implementing the roadmap would require participation from a range of stakeholders:

- **Steel manufacturers** need to drive the change to make the sector greener with initiatives ranging from efficiency to technology.

- **Government** needs to set policy and frameworks to provide the right signals, trust, assurance, and financial incentives to support the transition.

- **Major consumption sectors**, such as construction and automobiles, need to commit to procuring green steel, assuring demand creation, and motivating manufacturers.

- **Financing institutions** need to fast-track green investments to spearhead the transition. To support manufacturers, they can provide concessional finance and help establish a green steel development fund.

- **Research-oriented institutions such as think tanks and academia** can play a role across the value chain. From policy support to research and implementation of pilot projects, think tanks can help structure and support the green steel ecosystem. Academia also needs to lead R&D alongside industry to find advanced techno-economically feasible and cleaner solutions.

India's steel sector holds great potential to support the country in deep decarbonisation and achieving climate goals. Going forward, the collaboration of stakeholders, implementation of roadmap action points, and effective monitoring will be essential to making the greening of steel a success.

Introduction

Emerging Importance of Decarbonising the Steel Sector

The steel sector plays a crucial role in economic development, infrastructure build-out, and urbanisation.[2] Because of heavy reliance on fossil fuels, the global steel sector currently is responsible for approximately 7%–9% of global emissions. By 2050, the sector's contribution to global emissions is projected to increase slightly, despite declining total emissions.[3] Thus, to align with the international climate goal of staying below 1.5°C, decarbonising the steel sector worldwide is essential. India, the world's second-largest producer and consumer of steel, is the key to a successful global transition.

Various factors necessitate India's transition towards the low-carbon steel sector:

1. **Climate targets:** Many countries have pledged to achieve net-zero emissions to align with a 1.5°C future.[4] At the 26th United Nations Climate Change conference (COP26) in 2021, India also announced its commitment to the 2070 net-zero target. Thus, recognising the need for action to achieve these ambitious climate targets, the Government of India will need to mitigate emissions from major hard-to-abate sectors like steel.[5]

2. **Energy security:** India's steelmaking routes require imported materials such as coking coal and natural gas,[6] which are subject to price volatility linked to global geopolitics.[7] With the expected domestic demand for steel and the potential for export markets, these imports would further grow. Switching to newer and cleaner technologies can lower dependence on imported fossil fuels, reducing import bills.[8]

3. **Economic and policy development:** Policymakers in India are excited by the prospect of decarbonising steel as it will allow them to position the country as an economical, low-carbon hub for steelmaking while promoting green jobs across the value chain.[9] Emerging technology options for decarbonising steel, such as green hydrogen, started to gain momentum with the announcement of the National Hydrogen Mission and the launch of the National Green Hydrogen Policy.[10]

4. **Sustainability goals:** Both steel producers and off-takers are committing to sustainability goals to reduce their carbon footprint as part of corporate social responsibility and environmental, social, and corporate governance efforts.[11] Steelmaking accounts for steel producers' Scope 1 and Scope 2 emissions and for steel off-takers' Scope 3 emissions.[iii] Hence, a steel off-taker attempting to reduce its Scope 3 emissions will aim to procure low-carbon steel from manufacturers, creating a demand-pull.[12]

5. **Investors and shareholder expectations:** Investors and shareholders are increasingly becoming climate conscious and are looking to invest in greener alternatives. Moreover, financial disclosure mechanisms like the Task Force for Climate Disclosure are creating more transparent channels for climate-conscious investors, which are demanding that steel producers start transitioning towards cleaner modes of production.

These developments require the country to develop an ecosystem for low-carbon steel. By trying to mainstream the conversation around decarbonising steel and creating a needed ecosystem for sectoral solutions, India has begun to kick-start efforts towards harnessing this opportunity to green the steel sector. To revolutionise the low-carbon steel transition, there is a need for long-term commitment and an action plan/roadmap for sustained green growth.

State of the Steel Sector in India

Economic growth, increasing population and urbanisation, and rising incomes will inevitably lead to rapid infrastructure expansion, resulting in increasing steel demand in the nation. Moreover, India's vision of self-reliance as part of the Atmanirbhar Bharat initiative is bound to boost domestic manufacturing.[iv] RMI has found that India's total finished steel demand could increase by around 80% to 197 Mt by 2030 and nearly 4.5 times to 527 Mt by 2050 from current levels (115 Mt in 2022).[v]

Correspondingly, based on current net exports of steel, crude steel production is expected to grow at similar rates, reaching 576 Mt by 2050 (see **Exhibit 1a**, next page).

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iii Scope 1 emissions are the direct emissions that occur from sources that are owned or controlled by a company, for example, combustion of fossil fuels; Scope 2 emissions are indirect emissions associated with the purchase of electricity, heat, steam, and cooling; and Scope 3 emissions come from sources that the company does not control. They are also indirect, for instance, from extraction and production of purchased materials (GHG Platform 2021, https://www.indiaghgp.org/explaining-scope-1-2-3).

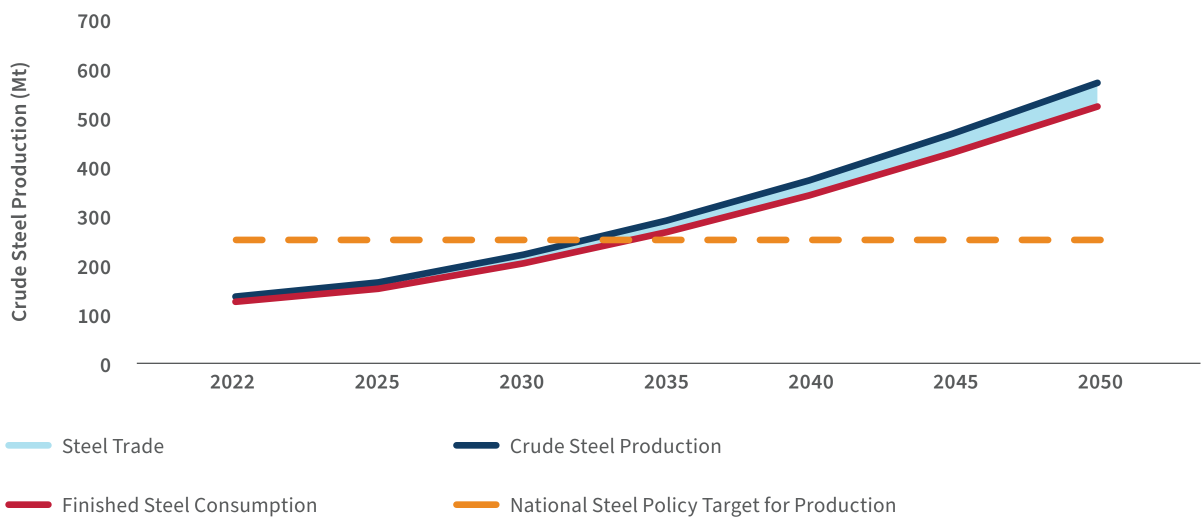
iv Atmanirbhar Bharat Abhiyaan or the Self-Reliant India campaign aims to make the country and its citizens independent and self-reliant in all senses. It is based on five pillars – economy, infrastructure, system, vibrant demography, and demand.

v Total finished steel demand represents domestic demand and net imports for the country.

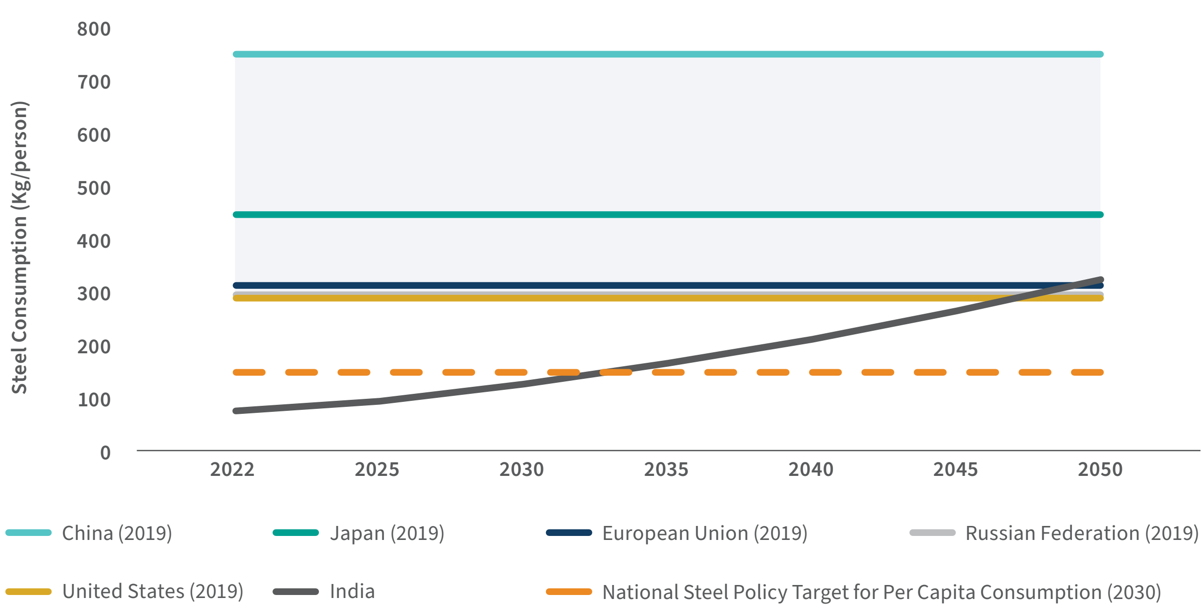
India's per capita steel consumption is significantly lower than that of peer nations and the world's average (233 kg per person) (see **Exhibit 1b**). With growing income and demand across various sectors, India's per capita steel demand is estimated to reach around 130 kg per person by 2030 and 321 kg per person by 2050 (about four times the current level). Despite this growth, India's per capita steel consumption is not expected to be on par with the 2019 levels of the European Union, Russia, and the United States until mid-century.

Exhibit 1 India's Crude and Finished Steel Growth 2022–50

1a. Steel Sector Growth in India



1b. Per Capita Steel Consumption across Countries



Source: RMI analysis

Currently, steel in India is produced by conventional methods such as the blast furnace–basic oxygen furnace (BF-BOF) and direct reduced iron–electric arc furnace (DRI-EAF).[13] Both primarily use coal. However, steel producers are moving towards the DRI-EAF with natural gas, which can reduce emissions intensity by nearly 50%.[14]

The heavy reliance on fossil fuels for steel production resulted in nearly 320 Mt CO_2 emissions in 2022 (approximately 12% of India's total CO_2 emissions). If the situation remains progress as usual (PAU), emissions will grow nearly threefold, reaching almost 900 Mt CO_2 in 2050. Hence, to lead the steel sector towards a low-emissions pathway, it is imperative to kick-start a sector-wide transition targeting a host of emerging technology options.

Towards Decarbonising Steel in India

Many factors are converging to shift the focus to greening the steel sector globally and in India. Multiple technology pathways also could enable this transition. Some include improving the efficiency of the conventional BF-BOF process, adopting green hydrogen,[15] adopting renewable energy, and adopting carbon capture and storage (CCS) and CCUS technology with BF-BOF or DRI-EAF.[16] Exhibit 2 provides further details on low-carbon steelmaking technologies considered in this analysis.

Exhibit 2 Conventional and Low-Carbon Steelmaking Routes Considered in This Analysis

Steelmaking Routes	Description	Emissions Intensity ($t\ CO_2/tcs$)
Conventional BF-BOF	The conventional BF-BOF depends heavily on coal for its processes, including reduction and energy needs. The use of electricity is limited in this route. Feed consisting of iron ore and coke is prepared via pelletising and sintering, integrated with coke ovens. Feed goes into a blast furnace producing molten iron/hot metal processed in a basic oxygen furnace to make steel.	2.78
Best Available Technology (BAT) BF-BOF	There is a potential for adopting best-in-class technologies to improve the efficiency of conventional BF-BOF technology.	2.08
BAT BF-BOF + CCUS	BAT BF-BOF + CCUS adopts CCUS in BAT BF-BOF to further reduce emissions intensity by capturing carbon. The capture efficiency for CCUS is 90%.	0.61
Scrap-Based EAF	Steel can also be made with scrap instead of raw iron ore. Scrap is processed in the EAF to produce steel. Scrap-based EAF is one of the least emissions-intensive routes. However, the availability of scrap is a challenge, especially for India.	0.53
DRI-EAF	DRI-EAF represents the second major conventional technology in the Indian steel sector. This route continues to be coal-dependent for reduction and energy needs. The EAF runs on electricity, which comes from fossil fuel–heavy sources.	2.79
DRI-EAF + Natural Gas	DRI-EAF can use natural gas instead of coal; however, it requires significant equipment changes, such as shafts. Natural gas is the primary source of energy and reductant, whereas the EAF continues to operate conventionally on electricity from a fossil fuel–dependent source.	1.38

Exhibit 2 Conventional and Low-Carbon Steelmaking Routes Considered in This Analysis (continued)

Steelmaking Routes	Description	Emissions Intensity ($t\ CO_2/tcs$)
DRI-EAF + H_2	Hydrogen-based steel is the most discussed and considered the most promising route for steelmaking. The primary reductant, coal or natural gas, is replaced with hydrogen. However, some amount of natural gas is still needed to keep the system running. All additional heating requirements are assumed to be met with electric heating. The produced DRI is then processed in the EAF.	0.67
DRI-EAF + CCUS	The DRI-EAF running on natural gas is equipped with CCUS with the capture efficiency of 90%.	0.41
DRI-EAF + Biomethane	A DRI-EAF route in which natural gas used across the plant is blended in equal proportions with biomethane.	1.21
Electrolyser-EAF	Iron is made via direct electrolysis of molten iron ore or a high-temperature (>1,550°C) solution of it, like today's aluminium smelting. Molten iron is fed into the EAF to turn iron into steel.	3.86
Electrowinning-EAF	A direct iron ore electrolysis process is followed in which iron ore particles are suspended in an aqueous alkaline solution at around 110°C. Current passing through the solution breaks down ore into oxygen and iron, which crystallises on a cathode. Iron is fed into the EAF to turn iron into steel.	3.59
Smelting Reduction	Smelting reduction is a process in which liquid hot metal is produced from iron ore and coal, eliminating the coke-making step required for a traditional BF. This route is based on HIsarna, a type of smelting reduction in which iron ore fines are injected at the top of a cyclone converter furnace along with pure oxygen and coal.	2.35
Smelting Reduction + CCUS	Smelting reduction is coupled with CCUS technology with 90% capture efficiency.	0.36

Notes: 1) Grey tabs show conventional steelmaking routes; green tabs show green routes with significantly lower emissions intensity than conventional ones. 2) Intensities are for 2022 and would decline in the future because of increased system efficiencies and improved grid emissions factors. Intensities are estimated with a bottom-up approach, based on reference plants and sectoral averages.

Source: RMI compilation

Adopting these technologies for greening India's steel sector will be approached with three anchors – innovation, investment, and inclusiveness. Innovation would lead to maturing the advanced mitigation options sooner, investment would help achieve scale for low-carbon steel technologies, and inclusiveness of stakeholders would strengthen the low-carbon steel ecosystem, mitigate risks by sharing approaches, and plan for a road to deep decarbonisation of the sector.

Within this context, this report explores the economics of alternative steelmaking routes and possible parity timelines, the adoption of cleaner technologies by reducing technological and market barriers and an understanding of decarbonised steel's international and domestic competitiveness. The report was developed through a techno-economic analysis of the steel industry and its decarbonisation potential and by interviewing major steel producers and industry experts. The report presents a detailed roadmap for deep decarbonising of the steel sector in India, focusing on near- to long-term action points across three pillars – policy, technology, and finance – while highlighting the roles of different stakeholders.

Assessment of Decarbonisation Pathways

RMI conducted an in-depth assessment of steel production technology pathways under different scenarios to understand the decarbonisation potential of the steel industry in India and the benefits it can bring to the environment and the economy.

Scenario Overview

In this report, we explore three key scenarios – PAU, Hydrogen (H_2) Economy, and Net-Zero-Aligned – to understand the outlook of the steel sector in India by 2050 (see Exhibit 3). The scenarios consider the implications of different pathways of techno-economic and policy choices. Additionally, exploring different scenarios helps identify levers of action while highlighting uncertainty in long-term emissions pathways as regards near-term decision-making.

Exhibit 3 Scenario Descriptions for Understanding the Outlook of the Steel Sector in India

Scenario	Description
PAU	The Indian economy continues to grow towards the Atmanirbhar Bharat vision. With economic growth, the iron and steel sector of the economy expands significantly. Though there has been a focus on climate issues and green technologies, it continues to be challenging to scale green alternatives such as H_2 and electricity because of relatively high costs. Also, low-carbon steel production technologies such as hydrogen and CCS-based steelmaking are not commercially viable within this decade. For gas-based DRI-EAF, the economy continues to be dependent on imported liquefied natural gas and therefore is affected by expensive gas prices. Hydrogen-based DRI starts gaining momentum from 2030 onwards and reaches commercial maturity by 2050. Similarly, the smelting reduction process also reaches commercial maturity by 2050. CCUS technology is already gaining momentum and starts penetrating from 2030 onwards and is expected to reach commercial maturity by 2050. Emerging new technologies like electrolyser-based steelmaking are assumed to remain in the pilot phase and do not reach commercial scale in this scenario.
Hydrogen Economy	With increasing focus on decarbonisation of the steel sector and faster maturity of green hydrogen technologies, the Indian economy comes closer to its vision of becoming a hydrogen-based economy. Coal continues to be cheaply available, and gas continues to be expensive. Both electricity with higher renewable energy penetration and green hydrogen become available at relatively low prices. In terms of technological advancements, penetration of green H_2-based steelmaking starts from 2025 onwards but progresses slowly and reaches complete commercial maturity by 2040, a decade before PAU. Other technology improvements and commercialisation remain in line with the PAU scenario.

Exhibit 3 Scenario Descriptions for Understanding the Outlook of the Steel Sector in India (continued)

Scenario	Description
Net-Zero-Aligned	To align the Indian economy with the net-zero pathway while achieving interim low-carbon development goals, R&D and policy interventions are focused to bring breakthroughs and economic viability across technologies. Electricity (with a significant mix of renewable energy in the grid) and green hydrogen would reach ambitiously low prices such as H_2 being available at or below US$1/kg by 2030. Additionally, technologies like CCUS and electrolytic steelmaking reach maturity earlier than in the PAU scenario. To be on the pathway to net zero, an adequate policy push would be required to gradually transition away from conventional fossil fuel–dependent technologies. There would be a dedicated push for investment in green technologies such as green hydrogen and CCS/CCUS-based steelmaking. Additionally, conscious efforts would be made to move away from investments in conventional fossil fuel–based assets. The focus of the sector would be to scale low-carbon steelmaking faster and earlier than in previously described scenarios.

Source: RMI

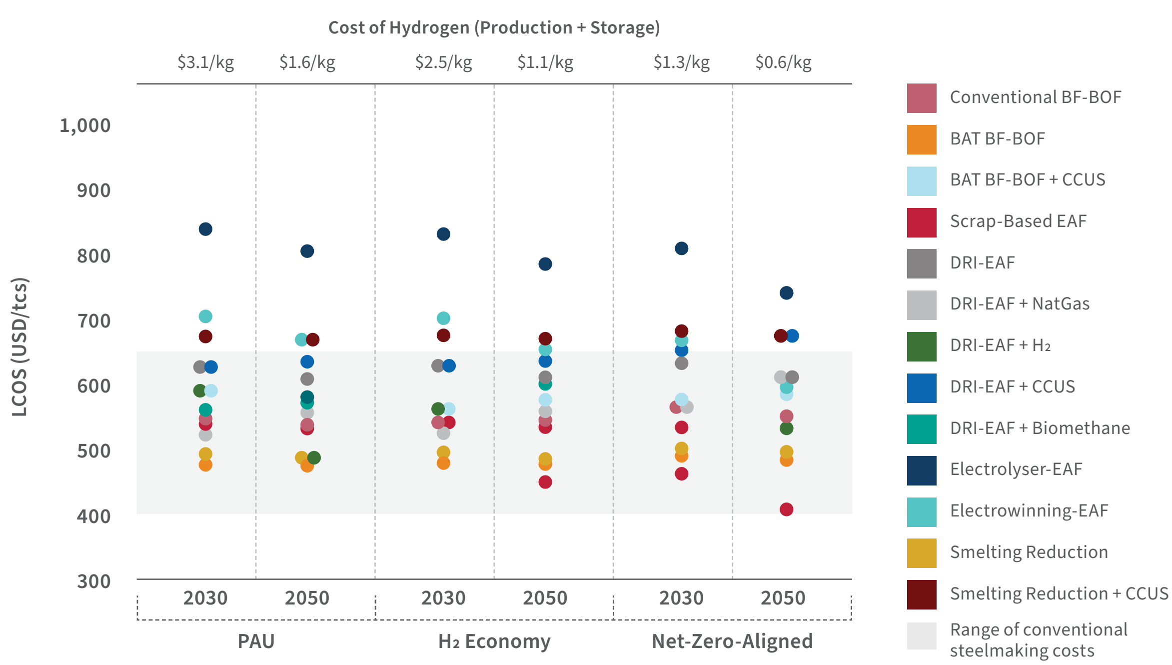
Key Findings from the Techno-Economic Analysis

Levelised Cost of Steel across Alternative Production Routes

The cost of steel production across routes is a function of capital cost levelised annually and the operations and maintenance cost comprising raw materials cost, fuel cost, labour charges, and other maintenance requirements.[17]

Currently, steelmaking from low-carbon routes such as green hydrogen, CCUS, direct electrolysis, and scrap is substantially more expensive than the fossil fuel–based conventional route of production.[18] The cost at which green hydrogen is available will be a significant determinant for the cost of steel production from the green hydrogen–based DRI route.[19] Green hydrogen cost is a factor in two key cost variables: the cost of the electrolyser and the price at which renewable electricity is available. In the long term, the availability of cheaper renewable electricity will be essential to decarbonise the steel sector. This will have an impact on the penetration level of this technology, which is necessary for steel decarbonisation. The analysis shows that the cost of hydrogen (production with storage) in the PAU scenario is expected to be more than US$3/kg in 2030 and will decline by nearly 50% by 2050. Corresponding to this hydrogen cost trajectory, green hydrogen–based steelmaking could reach cost parity with best available technology (BAT) BF-BOF only by 2050 (see **Exhibit 4**).

Exhibit 4 LCOS Parity across Steelmaking Routes



Source: RMI analysis

In the H_2 Economy scenario, the hydrogen cost trajectory is progressively optimistic. The cost of hydrogen (including storage) is estimated to reach US$1/kg by mid-century. Following this trajectory, by 2050, green hydrogen–based steelmaking will be cheaper than all other steelmaking routes, including the BAT BF-BOF route. With the declining cost of hydrogen, gradual penetration of green hydrogen–based DRI steel is expected within the steel sector (see **Electrification, Green Hydrogen, and CCUS – Critical Levers to Make India a Low-Carbon Steel Economy,** page 24).

Looking at sector growth and the Net-Zero-Aligned scenario, it would be essential to achieve a US$1/kg cost of hydrogen production by 2030 to make green hydrogen–based steel more economically attractive as compared with conventional BF-BOF or DRI-EAF routes. In the Net-Zero-Aligned scenario, the optimistic H_2 trajectory can help reach green hydrogen–based steelmaking cost parity with BAT BF-BOF by 2030. With the continued decline in green hydrogen cost by 2050, the price of steel produced using green hydrogen would be more than 20% cheaper than BAT BF-BOF.

Low-Carbon Steel Production Pathways and Emissions Reduction

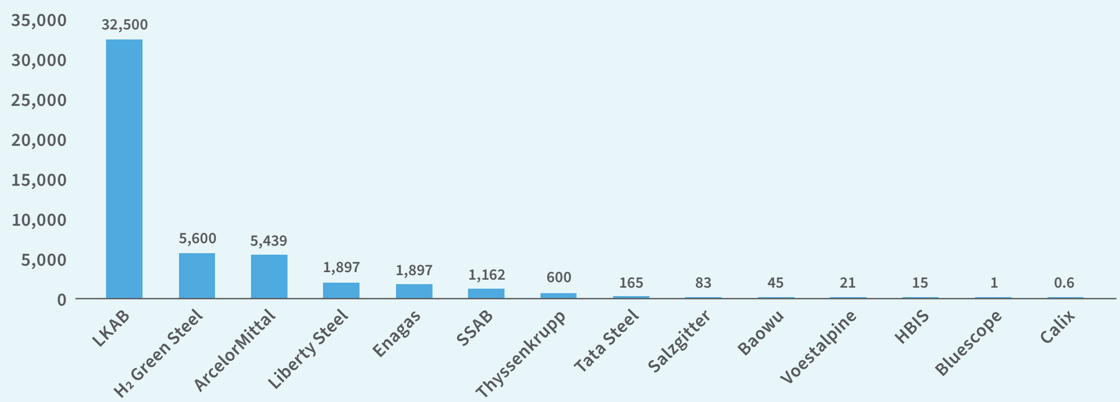
Supporting massive steel demand would require significantly more crude steel production capacity in the economy. Additionally, the retirement of existing capacities over time would further increase the need for new investments. By 2040, nearly all the current capacity is expected to retire. By 2030, nearly 150 Mt of crude steel production will be added, which will lead to more than 575 Mt of total crude steel production by 2050. Thus, there is an opportunity to move new investments towards being green and sustainable with policy, technology, and economic interventions.

Box 1: European Union Leading Global Green Steel Investments

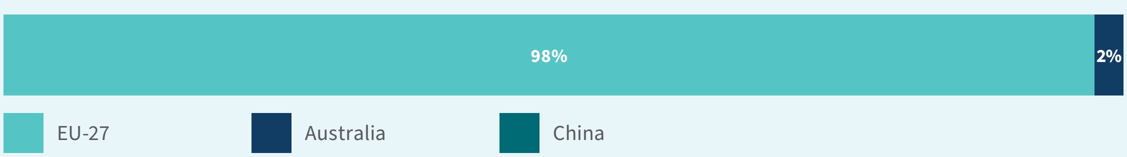
With the increasing urgency to mitigate global emissions, green steel is attracting attention worldwide. More than 50 projects worth nearly US$50 billion have been announced. However, all regions are not experiencing similar momentum. More than 98% of the announced investments are in the European Union, and Swedish steel producers LKAB and H_2 Green Steel account for more than 75% (see **Exhibit B1**). Other producers, such as ArcelorMittal and Liberty Steel, plan to contribute to nearly 15% of investments. Commitments to 2050 net-zero and policy instruments such as the European Green Deal, Carbon Contracts for Difference (CCfD), and carbon pricing make the European ecosystem conducive to the green steel transition.

Exhibit B1 More Than 98% of Announced Green Steel Investment Is Concentrated in the EU

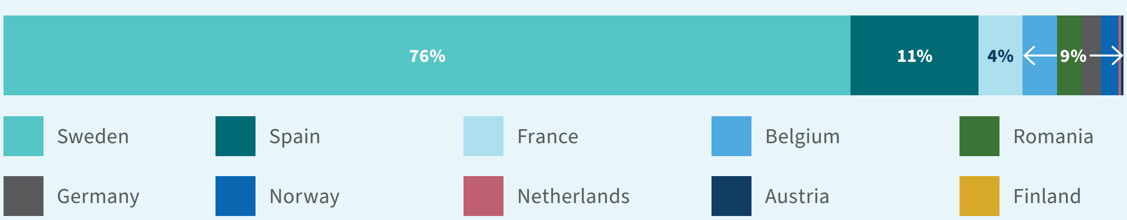
Company-Wise Investment Announcements for Green Steel



More Than 98% of Investments Are Announced in European Union

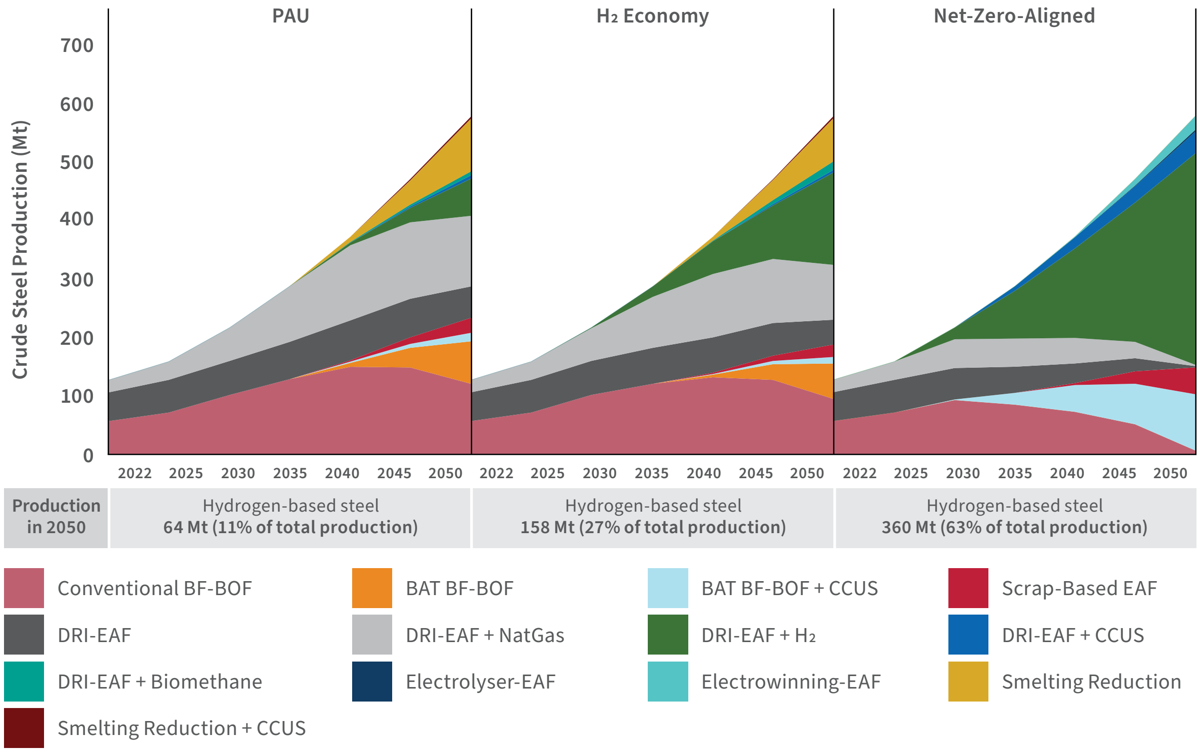


Sweden has Most Investments Announced in EU-27



Source: RMI compilation using data from Vogl et al., Green Steel Tracker, Leadership Group for Industry Transition, 2021, https://www.industrytransition.org/green-steel-tracker

Exhibit 5 Crude Steel Production through Different Technological Routes across Three Scenarios



Source: RMI analysis

In the PAU scenario (see **Exhibit 5**), most crude steel will be produced via fossil fuels through 2030. Post-2030, some green initiatives by steelmakers and policies by the government will push the share of greener technology, but still, around 80% of crude steel production will be fossil fuel based by 2050. BF-BOF will continue to dominate the production mix (around 34%), with gas-based DRI accounting for 21% of the production mix and only 11% hydrogen by 2050. Overall, the energy mix of the sector remains coal-dominant with more than a 60% share, followed by natural gas holding a 16% share, and only 5% of the sectoral energy mix would be supported by hydrogen. Correspondingly, emissions will also increase 2.8 times, reaching almost 900 Mt CO_2 per year by mid-century.

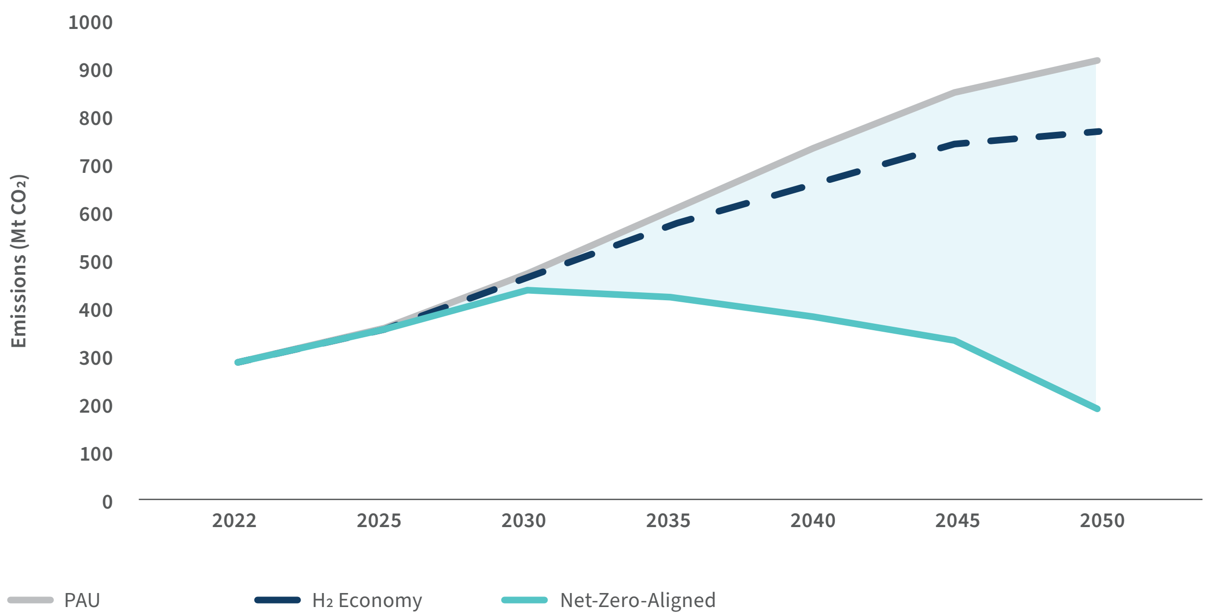
On the other hand, a conducive ecosystem for encouraging India's hydrogen economy could help transform the sector towards low-carbon steel production. In the H_2 Economy scenario, hydrogen-based steelmaking starts penetrating in a limited manner by 2030. This is because the green hydrogen cost remains on the higher end. However, green hydrogen–based steelmaking covers a significant portion (27%) of total steel production by 2050. H_2-based steel production replaces fossil fuel–based steelmaking, especially gas-based. In this scenario, fossil fuel–based production will decline by 15% from 80% in PAU to 65% in the H_2 Economy scenario, and emissions also will decrease by 15% in 2050.

Reaching a US$1/kg hydrogen price by 2050 would reap significant benefits for the sector's green energy transition. However, dedicated climate-conscious efforts are needed to achieve a low-carbon steel economy much earlier than in the above scenarios. In the Net-Zero-Aligned scenario, we assume it will be essential to achieve a US$1/kg H_2 production cost (US$1.3/kg including storage) by 2030. It is also assumed that the investment in fossil fuel technologies will continue to decrease over the years and, beyond 2040, no new fossil fuel–based production will be introduced. With the intended discouragement of fossil fuel technologies, this scenario suggests that fossil fuel–based steel production would be limited to just 2% by 2050. Most of production will be with hydrogen-based steel, which will have more than a 60% share, followed by 23% fossil fuel–based CCUS-equipped production. This scenario assumes a conservative approach towards scrap, considering the relatively newer infrastructure of the country, resulting in 8% scrap-based steel production by 2050.

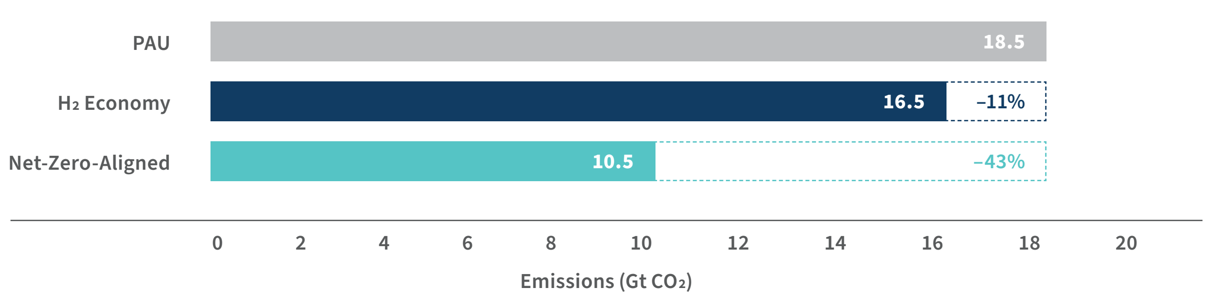
Compared with the PAU scenario, the steel sector in the Net-Zero-Aligned scenario would be emitting 75% less CO_2 in 2050 (see **Exhibit 6a**). The residual emissions of 227 Mt per year from the sector would further decline from 2050 onwards, aligning with the 2070 net-zero target.

Exhibit 6 Emissions Trajectory and Cumulative Emissions across Scenarios

6a. Emission Trajectory of Iron and Steel across Scenarios



6b. Cumulative Emissions from 2022–2050 across Scenarios



Source: RMI analysis

Per RMI's analysis, with growing steel demand, cumulative emissions between 2022 and 2050 from the steel sector are expected to reach nearly 18.5 Gt CO_2 (see **Exhibit 6b**, previous page). However, India can cumulatively reduce around 2 Gt CO_2 and 8 Gt CO_2 between 2022 and 2050 in the H_2 Economy and Net-Zero-Aligned scenarios, respectively.

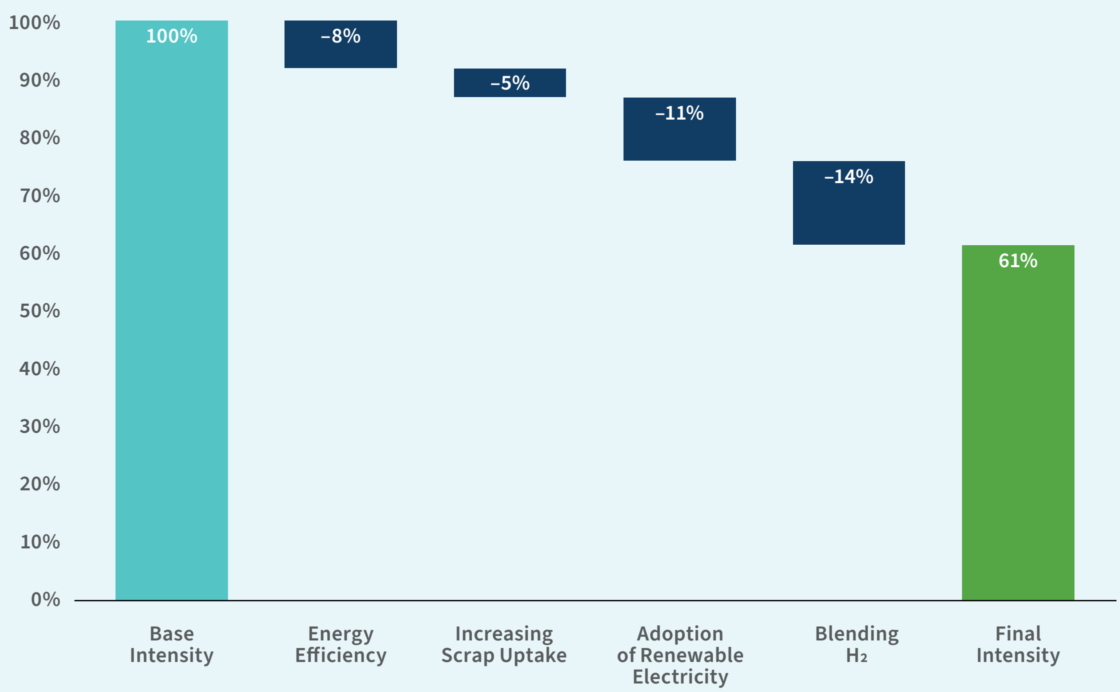
Box 2: Existing Assets Can Also Contribute to India's Low-Carbon Steel Journey

In India, steel production is dominated by two primary routes: BF-BOF and DRI-EAF/induction arc furnace (IAF). Because of limited scrap availability and techno-economic barriers to adopting green alternative fuels like hydrogen, the sector is heavily fossil fuel dependent. Most energy and feed demand is met by coal, with some gas. We have shown the implications of increasing new low-carbon steel investments across scenarios to transform India towards a decarbonising steel sector.

In the near term, decarbonising existing assets would supplement steel emissions reduction until advanced technologies reach commercial viability. To reduce the emissions intensity of steelmaking based on current conventional assets, there are four major opportunities: energy efficiency, increasing scrap uptake, adoption of renewable energy, and blending H_2 (see **Exhibit B2**).

Exhibit B2 Opportunities to Make Current Assets Green

Sectoral Emissions Intensity Reduction across Wedges for Existing Capacities



Source: RMI analysis

The overall current intensity (in 2022) of the Indian steel sector is nearly 2.54 t CO_2/tcs, described as base intensity in **Exhibit B2**. India's steelmaking, on average, is more inefficient and, thus, emissions-intensive than other countries. lmproving efficiency of processes offers a great opportunity to maximise system gains. In our analysis, we assume that increasing efficiency of the system could help reduce the specific energy consumption of each route by 10%, which in turn helps reduce the emissions intensity of steelmaking in India by nearly 8%.

Scrap-based steelmaking does not need to follow the whole process of iron reduction and processing. Thus, it requires less energy than conventional routes. The share of scrap blending currently is nearly 10%; however, the share can increase to 25%. With this increase in scrap uptake, emissions intensity can be further reduced by 5%. Across routes, BF-BOF uses less electricity than DRI-EAF, which requires electricity as a key input.

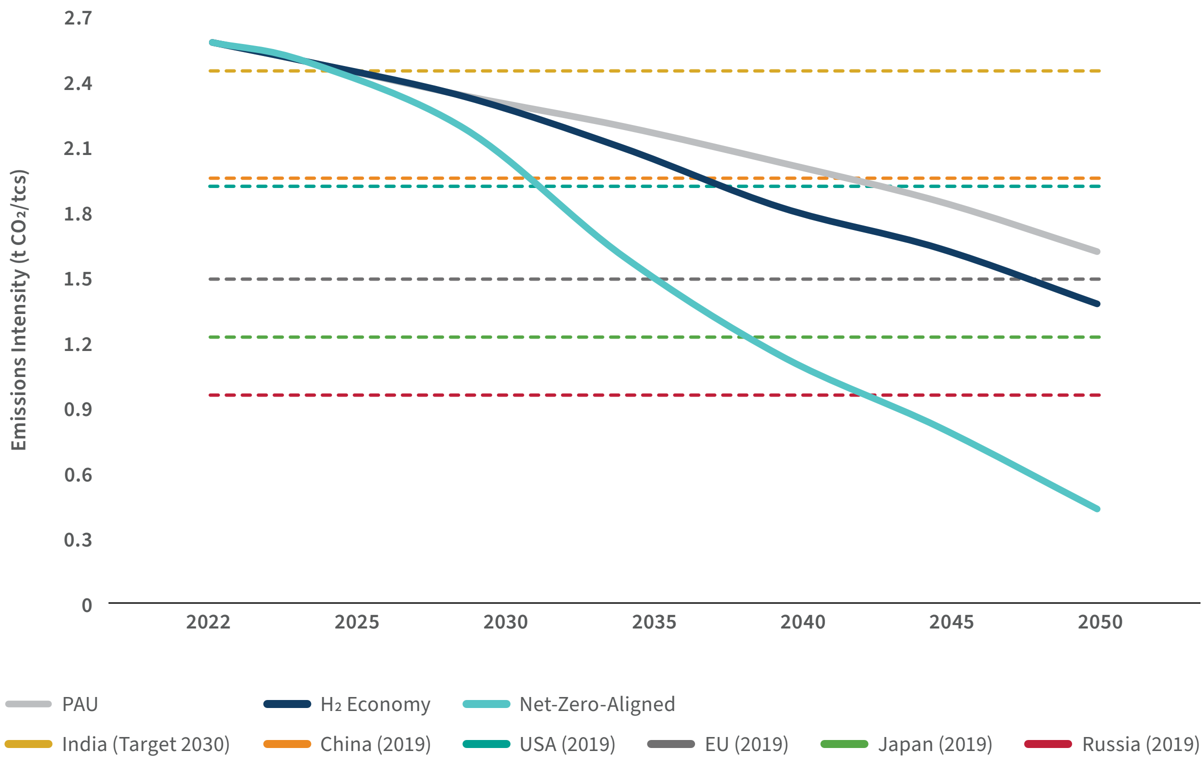
Additionally, steel manufacturers can consider meeting all their electricity demand with renewable energy. This action could significantly reduce the emissions intensity of the sector by 11%. And last, blending green hydrogen up to 50% with conventional fuel in the iron reduction process would decrease coking coal consumption, reducing emissions intensity by 14% more. Blending H_2 in BF-BOF requires significant changes in infrastructure to incorporate green hydrogen blending beyond a certain extent. Even in DRI-EAF, dedicated hydrogen-based furnaces are needed. Overall, tapping these opportunities could reduce sectoral emissions intensity by around 40% to 1.5 t CO_2/tcs, which could play a crucial role in accelerating India's low-carbon steel future.

Existing initiatives include the perform, achieve, and trade (PAT) scheme, which is an energy-efficiency-promoting mechanism in which energy-saving certificates are given as incentives to industries that overachieve their targets. PAT has played a key role in driving energy efficiency efforts in the country. More recent efforts by the Government of India's Bureau of Energy Efficiency would transition from PAT to the carbon market, further facilitating emissions mitigation efforts in existing steel units.

Advancing India's Steel Decarbonisation

India has made commitments to decarbonise the steel sector based on the emissions intensity of steel (EIS). Currently, the EIS in India is nearly 2.54 t CO_2/tcs, with a target in place by the Government of India's Ministry of Steel to reach 2.4 t CO_2/tcs by 2030.[20] According to RMI's analysis, no additional efforts will be needed to reach the proposed target; rather, it can be achieved by 2027, three years early (see **Exhibit 7, next page**). Progress and efforts such as energy efficiency measures, increasing uptake of scrap, and renewable energy, proposed in the PAU scenario, will be sufficient. In the long term, by 2050, even in the PAU scenario, India's steel sector emissions intensity is expected to decline by nearly 40% from current levels. Promoting a green hydrogen–conducive ecosystem would help decrease the emissions intensity of the sector to 1.3 t CO_2/tcs by 2050.

Exhibit 7 Emissions Intensity of the Iron and Steel Sector across Scenarios



Source: RMI analysis

However, the PAU and H_2 Economy trajectories deviate significantly from the ideal Net-Zero-Aligned pathway. To stay on that pathway, the currently proposed target by the ministry must be advanced to 2025, and the 2030 target should be decreased to 2.1 t CO_2/tcs from 2.4 t CO_2/tcs. Additionally, to provide the right policy signal and highlight government commitment to private players, a long-term vision should be put in place to reduce the emissions intensity of the sector to 1.0 t CO_2/tcs by 2040 and 0.4 t CO_2/tcs by 2050.

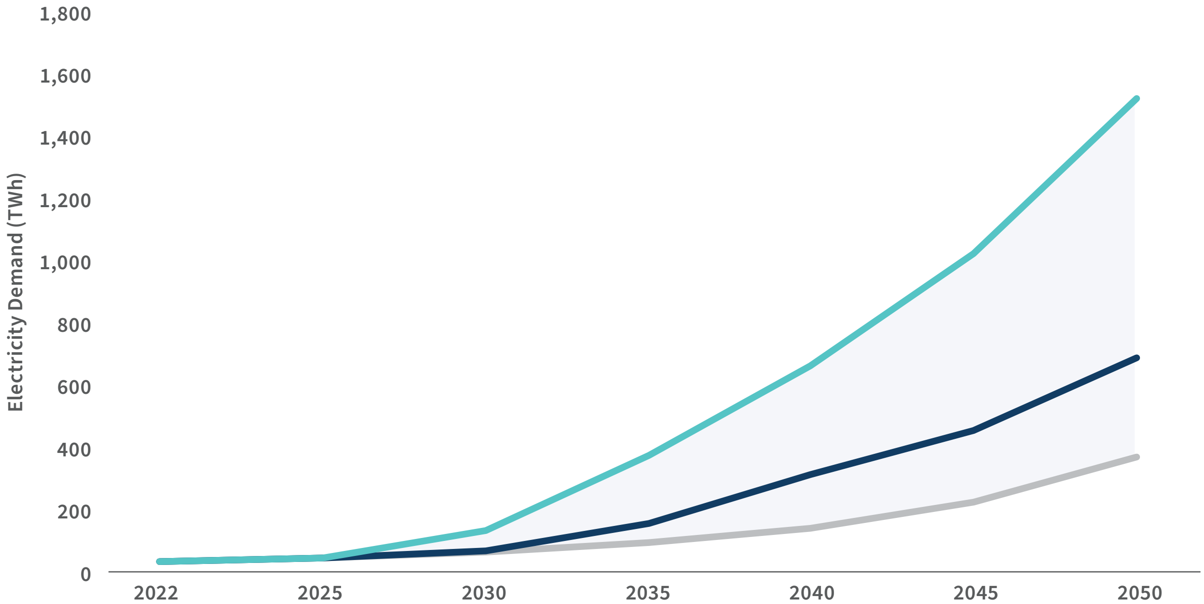
Electrification, Green Hydrogen, and CCUS – Critical Levers to Make India a Low-Carbon Steel Economy

The sustainability and momentum of decarbonising India's steel sector depend on three crucial pillars: electricity, green hydrogen, and CCUS.

Greater electrification with significant integration of renewable energy is the first critical lever. Increasing penetration of EAF will be the direct means of electrifying the steel industry in India, while the production of hydrogen using renewable energy will be the indirect means of electrification. RMI's analysis suggests electricity demand in 2050 could range 8 to 30 times higher (see **Exhibit 8**, next page) than the alternative pathways explored in this study. One of the primary reasons for such a range in electricity demand is the uptake of EAF-based technologies.

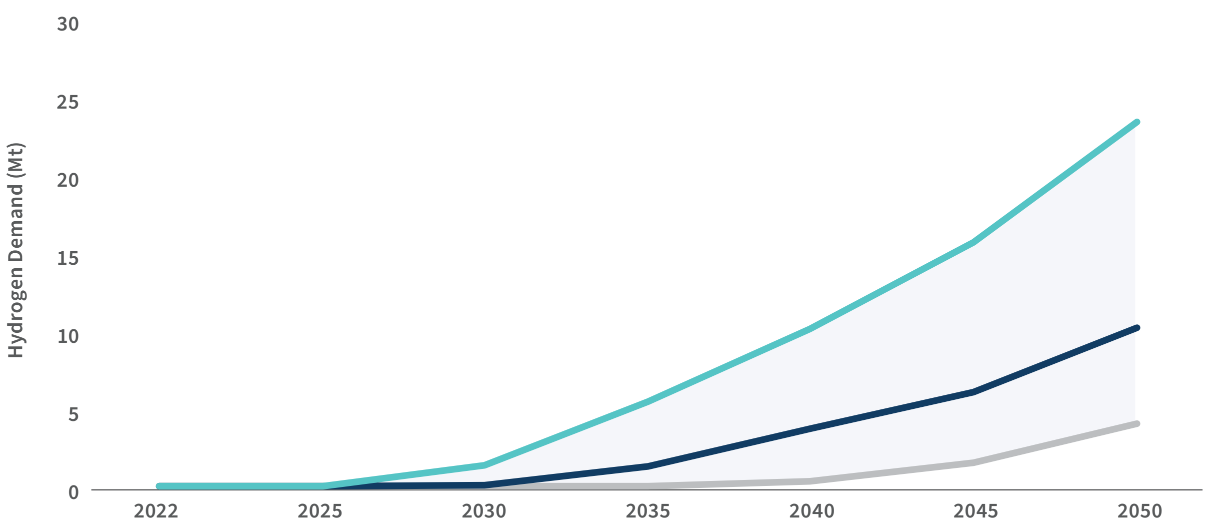
Exhibit 8 a) Electricity Demand across Scenarios and b) Hydrogen Demand across Scenarios

8a. Electricity Demand across Scenarios



Note: This electricity demand includes requirement for producing hydrogen.

8b. Hydrogen Demand across Scenarios



Note: Electricity demand in graph on the left includes the requirement to produce hydrogen.

Source: RMI analysis

The second critical lever is green hydrogen. It is crucial to India's steel sector for the country to become a hydrogen economy. Currently, India consumes nearly 6 Mt per annum of grey hydrogen, mainly in fertilisers and refineries, and there is no uptake in the steel sector. Going forward, this trend will change with the increasing availability of green hydrogen. Our analysis suggests that India's green hydrogen demand from the steel sector would range from 4 to 24 Mt based on the scenario pathway and policy direction the country chooses to follow. Green hydrogen demand would be three to six times higher for the H_2 Economy and Net-Zero-Aligned scenarios, when compared with the PAU scenario. In the Net-Zero-Aligned scenario, green hydrogen can meet more than 40% of the energy demand of the sector. To meet this hydrogen demand in 2050 from the steel sector alone, the electrolyser capacity of the country must reach 224 gigawatts (GW). Assuming this green hydrogen is driven only by solar power, almost 575 GW of solar capacity will be required by 2050, up from the 40 GW requirement in 2030.

The third critical lever for making the low-carbon steel economy possible is CCUS, which can provide a lifeline to existing and upcoming fossil fuel investors while simultaneously helping them cut emissions. The technology will never be considered a green signal for fossil investments, yet it does provide an opportunity for the economy to grow while green technology breakthroughs like hydrogen reach commercial maturity. Our analysis found that, across scenarios, CCUS-based production could range from 4% in the PAU scenario to more than 20% in the Net-Zero-Aligned scenario. By adopting CCUS, estimates suggest, the economy could avoid close to 1.6 Gt CO_2 of cumulative emissions (2022–50) in the Net-Zero-Aligned scenario.

Barriers to Decarbonising India's Steel Sector

Even though this analysis is optimistic about the potential of green technologies to decarbonise steel, a host of barriers exist that will need to be addressed to make the green steel economy a reality in India. Extensive consultations with the stakeholders have revealed the following key barriers:

1. **No clear definition of green steel:** Globally, there is no consistent definition of green steel. However, there are institutions like ResponsibleSteel leading efforts to define the term. In India, based on stakeholder discussions, green steel is a subjective term that is open for interpretation across producers and geographies. This inconsistency would lead to difficulty in global commodity trade and domestic markets for green steel products. With the growing uptake of green hydrogen and the potential demand for green hydrogen-based steel, there will need to be clear definitions for green steel from both producers' and consumers' perspectives.

2. **Limited efforts in green hydrogen–based steel manufacturing:** The cost of green hydrogen is significantly higher than grey hydrogen and other sources of hydrogen production. Our analysis suggests that, to be on a net-zero pathway, reaching US$1/kg of green H_2 by 2030 is essential. India has globally competitive renewable energy costs, which will make green hydrogen an indigenous and affordable energy source for the country. However, as of now, there are no green hydrogen–based steel projects planned in the country. Without large-scale projects, achieving the low-cost hydrogen price point by 2030 will be challenging. Dependence on imported electrolysers is another challenge.[21] Overall, the green hydrogen production infrastructure is inadequate to catalyse demand in the steel sector of India.

3. **Delayed maturity level of CCUS technology:** CCUS is an important lever that can significantly avoid emissions, but it has not reached full commercial scale.[22] Some critical challenges associated with CCUS are uncertainty around storage capacity, capture performance, upstream emissions, no clear utilisation opportunities, unclear carbon life-cycle benefit, extensive storage monitoring investments, policy divergence, and support for the continued use of fossil fuels.[23] Additionally, specific government-led identification and quantification of storage sites in India are lacking.

4. **Low stakeholder confidence in breakthrough technologies like H2 and CCUS:** Currently, India has no on-ground running pilots or clusters using green H_2 or CCUS.[24] Because of a lack of experience in adopting these technologies and the limited availability of India-specific business examples, stakeholders have yet to develop confidence in adopting these technological solutions.

5. **No mature market for green steel products and the inability of domestic consumers to pay a green premium:** For steel producers to invest in green steel production, they need a market for end products. India is a price-sensitive market where steel consumers would face challenges paying a premium for green steel as it would affect the competitiveness of their products if the incurred additional cost is transferred to consumers. Additionally, no demand for green steel exists, except for a few players announcing long-term steel consumption targets as part of the SteelZero initiative.[25,vi]

6. **Limited availability of scrap in developing economies like India:** Steelmaking using scrap is an important lever of decarbonisation. But the availability of scrap is a significant challenge in India as most of the nation's infrastructure is new, and nearly 70% is yet to be built. Also, the channels of scrap flow in India are informal. A few steps have been taken, such as a vehicle scrappage policy, to create formal channels.[26] However, more efforts are needed to make scrap available.

7. **Lack of concessional financing options:** The green steel transition will be an investment-intensive process. A massive share of India's green steel capacity will be built in the coming years. Steel producers will need concessional financing options to drive investments to green routes to support the transition. Currently, there are no mechanisms for large-scale concessional funding for steel producers.[27] Also, other financing mechanisms, such as carbon markets, sustainability-linked bonds, and green bonds, are not institutionalised in India.

vi SteelZero is a global initiative that brings together leading organisations to speed up the transition to a net-zero steel industry.

Roadmap to Greening the Indian Steel Sector

Based on our techno-economic analysis and consultations with industry stakeholders and experts, we have identified five key levers to decarbonise the steel sector in India, along with associated opportunities and challenges. Later in this section, we propose a roadmap/action plan to make the low-carbon steel economy a reality in India with actionable steps relevant to stakeholders.

Key Levers to Decarbonise Steel

As discussed in the previous section, RMI's analysis suggests that green hydrogen, renewable electricity, and CCUS will be the key levers in the steel decarbonisation journey in India. In addition, the value proposition offered by increasing scrap utilisation and energy efficiency improvements is also crucial and cannot be undermined. To realise the benefits of these levers, there is a need to take dedicated actions to make them techno-economically viable in the Indian ecosystem (see **Exhibit 9**, page 33).

Lever 1: Promoting Green Hydrogen Adoption for Steelmaking

Context: Green hydrogen–based steel is one of the cleaner routes to produce steel being discussed worldwide. As highlighted in *Low-Carbon Steel Production Pathways and Emissions Reduction* (see page 20), hydrogen-based steel is expected to dominate steel production in a net-zero India. However, to adopt it, the widespread availability of green hydrogen and big investments by the steel industry in infrastructure are essential.

Opportunity: The success of green hydrogen in the Indian economy and the steel industry will depend on developing a policy ecosystem, improving infrastructure, and flowing green investments. The Government of India's National Green Hydrogen Policy and the Green Hydrogen Mission will be foundational for developing the green hydrogen economy. Though the mission is expected to be holistic in scope and include incentives, more needs to be done to facilitate its implementation and help raise ambitions among stakeholders.

R&D is needed to reduce the cost of hydrogen to US$1/kg within this decade. Promoting domestic electrolyser manufacturing capacity at scale will help lower costs and enable economic development. Moreover, undertaking pilot projects and developing industrial clusters for the shared use of green hydrogen will generate confidence among stakeholders around green H_2-based DRI technology. Finally, the availability of green finance, such as green bonds and sustainability-linked bonds, will be the key catalyst for green H_2–based steel in India. Additionally, green hydrogen can be used for blending in existing units, which can help decarbonise existing assets (see **Box 2,** page 22).

Priority Actions:

1. **Waiving state electricity charges to make renewable electricity affordable for green hydrogen production:** Though India has one of the lowest renewable electricity tariffs, total cost is significantly higher because of state electricity charges. Because electricity is a concurrent list subject (under both central and state government control), the Government of India must lead and facilitate the waiving of electricity charges by state governments for green hydrogen projects, making prices more attractive.
2. **Promoting government-led pilots and clusters to demonstrate the success of the green hydrogen–based production process:** To build trust across stakeholders, the first line of action must come from the government. The Government of India can support pilots or the development of clusters to display political acceptability and support for low-carbon steel production processes such as green hydrogen–based steel.
3. **Ensuring availability of concessional financing options for the low-carbon steel transition:** Steel is a capital-intensive sector in which assets have long lifetimes, and the cost of the transition towards low-carbon steel will be massive. Either to put in new assets or retrofit older ones, money will be a key determinant of success. The Government of India should put policy frameworks and financing mechanisms in place to facilitate financing of the green steel transition in India.

Case Study

Location: Sweden

Overview: Hydrogen breakthrough ironmaking technology (HYBRIT) will replace coal-based blast furnaces with a green hydrogen–based DRI process.

Description: SSAB (a steelmaker), LKAB (an iron ore miner), and Vattenfall (a renewable energy provider) are collaborating in Sweden to test the feasibility of a new technology called HYBRIT. The first phase will include running trials to test the technical feasibility of this technology in a pilot plant in Lulea, Sweden. The second phase will focus on industrial-scale production of green hydrogen–based steel, starting in 2026. The initial results from the pilot phase indicate that the hydrogen-reduced sponge iron has superior properties compared with iron made with the natural gas–based DRI process.[28] When deployed at scale, this project has the potential to produce 1.2 Mt of crude steel annually and help reduce 14.3 Mt of CO_2e in its first 10 years of operation.[29]

Box 3: India's Potential to Lead Green Steel Exports

Worldwide, steel is consumed mostly by the building and infrastructure sector (52%), followed by mechanical equipment (16%), and the automotive industry (12%).[30] Growing climate commitments from the companies in these sectors highlight the potential demand for green steel. SteelZero is one such platform providing an opportunity to consumers and aims to ensure adherence and advance the procurement goals of green steel among its members.[31] Globally, many large consumers such as A. P. Moller–Maersk and Volvo Cars have announced commitments to use net-zero steel by 2050.[32] Additionally, regions including Germany, California, and the Netherlands have committed to procuring sustainable products, including steel.[33]

Green steel, in the near term, would be available at a higher cost than conventional steel, thus imposing a premium on consumers. While green steel demand matures in India and steel off-takers develop the capacity to pay a premium for green steel, steelmakers can plan for the export market for green steel in regions like the EU and United States in the near term. These nations could be a prime target audience because of their regulatory regimes and willingness and capacity to pay for green steel.[34] With upcoming cross-border tax mechanisms, stepping up their efforts to produce green steel could help Indian steelmakers improve their competitiveness in the international market. Indian players could cater to the green steel demand in developed nations like those in the EU and the United States, with many consumers moving for green steel products.

Lever 2: Switching to Renewables for Electricity Needs

Context: The current steelmaking processes use electricity to a limited extent. Going forward, the expansion of EAF routes such as green H2-DRI-EAF, scrap-based, and CCUS would result in massive electricity demand in the nation.

Opportunity: The conventional form of electricity generation and consumption can be replaced by adding new renewable energy capacity, or the demand can be met through renewable purchases. In addition to the interventions discussed in emerging greenfield capacities, replacing conventional electricity sources with renewable energy could help reduce emissions intensity by more than 10% in brownfield assets too. Additionally, a focus on emerging electrolysis-based steel could further help electrification in the long term. Future R&D investments and pilots could help electrolyser-based and electrowinning-based steelmaking reach better maturity levels.

Priority Actions:

1. **Promoting plant-level renewable purchase obligations mandating renewable energy–based electricity adoption in the steel industry:** The Government of India shall obligate steel players to consume renewable electricity through plant-level targets. Additionally, the targets to be set for plant-level renewable purchase obligations (RPOs) shall be kept ambitious. Fines and rewards mechanisms shall be in place to maximise efforts from steel players.

2. **Replacing fossil fuel–based captive capacity with renewable energy captive power plants:** The steel industry holds one of the largest captive fossil fuel assets to power its plants. The government, along with industry players, shall prepare a roadmap to transition from these assets to renewable energy. Adopting this will help industry players achieve plant-level RPOs and emissions intensity targets.
3. **Promoting R&D with respect to electricity-/electrolysis-based steelmaking to electrify the complete process and ensuring that electricity demand is met by renewable energy:** Direct electrification of the steel sector is difficult but not impossible. Electrolysis-based steelmaking routes are developed but need R&D support to scale. The Government of India and Indian industry players shall envision India as a technology co-innovator and provider instead of following the conventional approach of lagging on the innovation curve and taking the role of technology seeker.

Case Study

Location: United States

Overview: Boston Metal is developing a technology for converting iron ore into liquid metal using a direct electrolysis process.

Description: Boston Metal is working towards commercialising a technology that will use renewables-powered molten oxide electrolysis (MOE) to convert iron ore into liquid metal, ready for steelmaking. The process eliminates fossil fuel consumption, such as coal or natural gas. Boston Metal aims to position this as a technology solution for steelmakers to deploy at their plants and plans to commercialise the technology by 2026.[35] Electricity, which is the primary input, must come from renewable sources for maximum emissions reduction benefits. Once the MOE technology starts achieving scale, steelmakers can integrate renewable generation assets with this technology.

Lever 3: Promoting the Adoption of CCUS Technology

Context: CCUS is another well-discussed solution in hard-to-abate sectors like steel, as it gives steelmakers an opportunity to decarbonise by sourcing the same fuels until green technologies like H_2 reach maturity.

Opportunity: To adopt CCUS, establishing the carbon market, building a policy ecosystem, promoting pilots, and communicating guidelines for adoption will be essential. Considering the risks associated with this technology, the technology and policy ecosystem for CCUS might also need to be highly regulated. Currently, adopting CCUS ends up imposing a significant premium at the product level, and thus dedicated efforts are needed to reduce the cost of this technology.

Priority Actions:

1. **Adopting policy and regulatory frameworks to formalise the emerging carbon economy in India:** Multiple studies, including this one, have reported the inevitability of CCUS technology in decarbonising hard-to-abate sectors like steel. The Government of India shall put in place the policy and regulatory framework to define guidelines around the adoption and promotion of this technology, along with the storage and utilisation of captured carbon.
2. **Supporting the development of the carbon market in India:** Low-carbon technologies like green hydrogen or CCUS-based steel will need to have a carbon market in place to improve their competitiveness and fuel their adoption. The Government of India is kicking off a form of carbon market that is emerging from the existing PAT scheme. Efforts should continue towards developing a fully functional carbon market like the ones in Europe.
3. **Driving R&D and supporting pilots for demonstration of the technology:** The Government of India shall lead and support projects to demonstrate the success of CCUS technology while highlighting risks and their mitigation actions. Capturing and storing carbon is more challenging in practice than is being acknowledged. Supporting R&D will help mitigate the risks of the technology and speed up its commercialisation.

Case Study

Location: United Arab Emirates

Overview: The Abu Dhabi National Oil Company (ADNOC) has the largest and only fully commercial CCS facility in the iron and steel sector at Emirates Steel Industries (ESI) in Abu Dhabi.

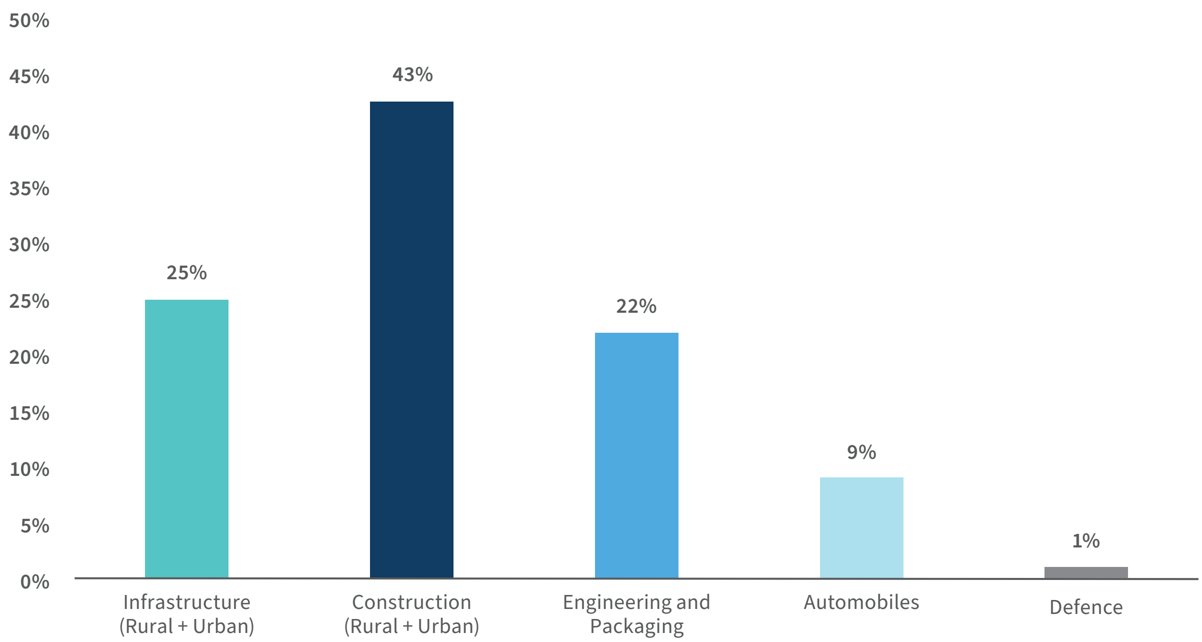
Description: Since 2016, ADNOC has been running the world's only iron and steel CCS facility at the ESI plant. The CCS plant can capture around 0.8 Mt of CO_2 per year. During the process, CO_2 is captured from the DRI plant, using a traditional MEA absorption/recovery system as part of reducing gas recycling leading to a CO_2-rich (>99%) waste stream.[36,vii] The CO_2 sourced from the ESI facility is sent to the compression and dehydration unit and then transported through a 43-kilometre pipeline to the Rumaitha oil field for injection to be used for enhanced oil recovery.[37]

Lever 4: Increasing Scrap Utilisation

Context: Steelmaking using scrap is an important lever of decarbonisation. But the availability of scrap is a significant challenge. India's infrastructure is new, and nearly 70% is yet to be built. Also, the channels of scrap flow in India are informal.

Opportunity: In India, steel is consumed across various sectors, from infrastructure to defence. **Exhibit 9** highlights the share of steel consumption across sectors in India.

Exhibit 9 Steel Consumption by Sector



Source: RMI compilation using data from the Ministry of Steel, Government of India, Annual Report 2021–22

The recently announced scrappage policy for the automobile sector is the first step towards channelling scrap flow in the economy. Streamlining the flow of scrap at each stage will enable better planning and help develop a formal scrap market. Scrap is also one of the commodities that is not readily traded among

vii Aqueous monoethanolamine (MEA) solution is commonly used for post-combustion carbon capture via chemical absorption.

countries because all countries are depending on it to lower emissions intensity. Yet, long-term scrap trade agreements could help assure the availability of scrap.

Priority Actions:

1. **Expanding the scope of scrappage policy beyond the automobile sector to quantify and channel scrap in the country:** Scrappage policy for the automobile sector will be a game changer in closing the steel scrap recycling loop. But it will be essential to expand the scope of the policy beyond automobiles to the construction and infrastructure sectors, which consume a significant volume.
2. **Formalising the scrap recycling sectors by streamlining collection, valuation, distribution, and so forth:** In India, the flow of scrap is mostly informal and disaggregated in nature. To make scrap available from end-use sectors to the steel industry, the Government of India shall support formalising scrap flow and implementation of the aggregator model.

Case Study

Location: China

Overview: China plans to increase its use of steel scrap by 23% to 320 Mt by 2025.

Description: China is the largest steel producer, with an annual production of more than 1.03 Gt of crude steel in 2021.[38] Emissions from China's steel industry account for more than 16% of the country's total CO_2 emissions and 60% of global steel CO_2 emissions.[39] Because about 80% of China's iron ore relies on imports, the Government of China plans to increase its use of steel scrap by 23% to 320 Mt by 2025.[40] China is systematically expanding its scrap sources, including liberalising the import of high-quality scrap to reduce costs. Also, it plans to have more scrap available as steel products like cars, home appliances, buildings, and infrastructure from earlier waves of development are phased out.

Lever 5: Improving Energy Efficiency

Context: Energy efficiency has always been considered a low-hanging fruit for reducing energy demand and, thus, emissions from the sector. India's steel sector's energy consumption is well above the global average, thus highlighting the opportunity associated with energy efficiency improvements.

Opportunity: Making the PAT scheme more stringent is one way to benefit from this lever. Additionally, there is a need for clear guidelines to adopt BAT for greenfield investments and a nudge for consistent improvement in brownfield investments. In India, multiple plants continue to operate beyond optimal lifetimes, and need to be monitored and encouraged to be replaced with modern and greener routes of steelmaking.

Priority Actions:

1. **Making PAT targets stringent to direct steelmakers to adopt more energy efficiency measures:** The PAT scheme has been instrumental in driving energy efficiency efforts in Indian industries. Despite efforts, the Indian steel industry is significantly below the global average for efficiency, which offers a lot of room for improvement. PAT targets, therefore, can be more stringent to improve the efficiency of the steel industry.
2. **Informing guidelines for technology adoption in greenfield projects to ensure the adoption of BAT technology routes:** The Government of India shall put guidelines in place to promote the adoption of BAT. Authorities shall promote new investments towards BAT or less emissive routes of steelmaking.
3. **Regular maintenance monitoring and evaluation to ensure high operational efficiency of plants:** The guidelines shall strengthen the monitoring and evaluation of the implementation of energy efficiency measures across production units. Stringent disincentives shall be designed to make production units stick to proposed guidelines and suggested measures.

Case Study

Location: India

Overview: The Government of India's flagship scheme, PAT, for improving energy efficiency covers 163 iron and steel units in India (referred to as designated consumers).

Description: PAT is a market-based mechanism to drive large industries towards improving energy efficiency. The PAT scheme was launched in 2012 and completed three cycles by 2020. Energy-saving certificates are given as incentives to industries that overachieve their targets. These certificates can be traded in an energy exchange (the Indian Energy Exchange or Power Exchange India). Since the inception of PAT, 163 iron and steel units in India have participated. In the iron and steel sector, key measures included the installation of top recovery turbines and adopting a coke dry-quenching process.[41] Other measures included sinter plant heat recovery (power generation from sinter cooler waste heat) and a pulverised coal injection system in a blast furnace. Adopting these efficiency measures has helped reduce the emissions intensity of the sector from around 3.1 t CO2/tcs in 2005 to about 2.6 t CO2/tcs in 2020.[42]

Box 4: Emerging Carbon Market in India and Its Expected Implications for the Indian Steel Industry

The Government of India has taken two instrumental actions towards setting up a domestic carbon market: (1) drafting a blueprint for introducing a national cap-and-trade (C&T) system and (2) amending the Energy Conservation Act 2001 to provide a legal basis for the voluntary carbon credit system.

The national C&T system will be introduced in phases. This first phase aims to increase voluntary demand for carbon credits; the second phase aims to increase supply through emissions reduction projects; and in the third phase, the market will evolve into a mandatory C&T system. Section 14 of the Energy Conservation (Amendment) Act, 2022 grants the Indian central government or any authorised agency the power to issue “carbon credit certificates” for reducing carbon emissions to registered entities. These credits can then be sold.

India’s C&T market might follow a similar structure as the EU Emissions Trading Scheme (ETS). Over the years, the emissions cap for the sector will decrease, thus leading to a significant increase in the price of carbon. The emerging carbon market will help shape the carbon economy of the country and can support the commercialisation of steel decarbonisation technologies, such as CCUS, which are essential to achieve a net-zero steel sector in India. Additionally, carbon pricing would help improve the competitiveness of low-carbon technologies such as green hydrogen–based steelmaking or a renewables-based direct electrolysis process.

Action Plan towards Building a Green Steel Economy in India

A detailed roadmap targeting the green steel economy can help bring to fruition the actions suggested under each decarbonisation lever. This roadmap will help guide and reduce uncertainty around initiatives and actions, provide a detailed timeline to prioritise those actions, and highlight the roles of key stakeholders to enable a smoother uptake of policy, technology, and financing solutions. Based on the techno-economic scenario modelling analysis and discussions with industry stakeholders and experts, **Exhibit 10** presents the roadmap for greening the Indian steel industry.

Exhibit 10 Roadmap to Green the Indian Steel Industry – Ambitions and Actions

Objective	Timelines	Components	Key Stakeholder	Initiatives to Undertake
Establishing definitions and standards of green and low-carbon steel	Near term	Policy	Government, industry, financing Institutions	Developing stakeholders' consensus-led definitions and standards for green steel
		Policy	Government, industry, financing Institutions	Updating the National Steel Policy to align sectoral pathways with the national 2070 net-zero goal and the latest technology, policy, and financial advancements in the sector
	Medium term	Technology	Government	Formulating a green steel product labelling programme like star labelling for consumers choosing good-quality, low-carbon steel across different end-use sectors

Exhibit 10 **Roadmap to Green the Indian Steel Industry – Ambitions and Actions (continued)**

Objective	Timelines	Components	Key Stakeholder	Initiatives to Undertake
Advancing the uptake of alternative green energy sources like H_2 and renewable energy	Near term	Policy	Government	Mandating plant-level RPOs for greening electricity consumption among steel producers
		Policy	Government	Fast-tracking hydrogen purchase obligations to kick-start hydrogen consumption at the plant level for promoting H_2-based steelmaking
Announcing green steel procurement policy and targets to encourage market creation and demand aggregation	Medium term	Policy	Government	Advancing government-led public procurement of green steel for government-led infrastructure projects
		Policy	Government, industry	Aggregating green steel demand by mandating green steel procurement targets across private end-use sectors
		Policy	Government, industry	Promoting government-to-government conversations for unlocking potential green steel export markets for Indian producers
Supporting R&D to advance breakthrough technologies and solutions like H_2 and CCUS	Near term	Technology	Industry	Creating an industry-led technology coherence and development working group comprising stakeholders from hydrogen, green buildings, etc.
		Financing	Government, financing institutions	Establishing a Green Steel Development Fund to undertake dedicated R&D and pilot initiatives for green steel
	Medium term	Technology	Industry, government	Supporting R&D and pilot projects in associated decarbonising technologies, like H_2-based DRI steelmaking and CCUS
	Long term	Technology	Industry, government	Channelling dedicated R&D efforts towards commercialising and scaling of electricity-based steelmaking technologies such as electrolysers and electrowinning
Promoting alternative emissions mitigation actions through pilots and clusters	Near term	Technology	Industry	Promoting energy efficiency measures across the sector, especially in existing assets
		Technology	Industry, government	Supporting pilots and demonstration sites as success stories for wider adoption among industry players

Exhibit 10 **Roadmap to Green the Indian Steel Industry – Ambitions and Actions (continued)**

Objective	Timelines	Components	Key Stakeholder	Initiatives to Undertake
Promoting alternative emissions mitigation actions through pilots and clusters (continued)	Medium term	Policy	Government	Channelling and expanding the scope of scrappage policies to improve scrap availability for the steel sector
		Technology	Industry, government	Promoting a cluster-based approach for greening the steel production supply chain
	Long term	Policy	Government	Prioritising the iron and steel industry in carbon pricing while implementing a carbon market/ETS in India
Framing mechanisms and frameworks for financing the green steel transition	Near term	Policy	Government	Covering H_2-based steel production under the Production-Linked Incentive scheme[viii]
		Financing	Financing institutions	Exploring potential green bond and sustainability-linked bond mechanisms for funding low-carbon steel projects
		Financing	Financing institutions	Providing concessional funding to early movers for green steel production
	Medium term	Policy	Government	Facilitating development of adequate mechanisms to mitigate risks in newer low-carbon technology financing and increase the availability of resources
	Long term	Policy	Government	Adoption of a contractual/agreement framework such as Carbon Contracts for Difference in the EU for promoting transition for early and fast movers
		Financing	Government, financing institutions	Establishing financing channels and mechanisms to develop a national carbon economy/market that incentivises finance flows towards green steelmaking

Notes: (1) The timelines discussed in the above-described roadmap are as follows: near term means by 2024, medium term means by 2027, and long term means by 2030. (2) The key stakeholders under each action point are listed in the order of responsibility (high to low).
Source: RMI analysis

Overall, a collaborative approach towards initiatives will be essential. All the stakeholders have a role to play in the steel decarbonisation transition.

viii The Production-Linked Incentive scheme is the Government of India's scheme to give companies incentives on incremental sales from products manufactured in domestic units.

Conclusion

India's steel industry will grow exponentially, with expected crude steel production increasing beyond 550 Mt by 2050. However, continued dependence on fossil fuel energy sources in the long term could derail the economy from its national and global commitments towards climate action. Many industry players have been making diligent efforts to realise their net-zero commitment across proposed timelines.

The primary levers to produce low-carbon steel are green hydrogen, renewable energy, and CCUS. Currently, the cost of green hydrogen and the markup because of CCUS make it not viable to produce steel through these routes. Even the electricity demand in the steel industry is mostly met by captive fossil fuel–based power plants or from a heavily coal-dependent electricity grid.

For the steel industry to align with the net-zero target, electricity needs must be met from low-emitting sources, the US$1/kg cost of green hydrogen needs to be achieved by 2030, and breakthrough technologies such as green H_2 and CCUS must become techno-economically viable within this decade with improvements being observed over the coming decades. Additionally, a dedicated climate-conscious policy push to drive new investments towards low-emission routes instead of conventional fossil fuel–based BF-BOF or DRI-EAF will be critical. In the near term, brownfield assets can be improved by adopting efficiency measures, procuring renewable energy through power purchase agreements, increasing scrap utilisation, and blending green hydrogen into conventional processes as much as is possible. In the long term, the focus would be towards building the new fleet of low-carbon steel-producing assets to be dominated by green hydrogen–based DRI-EAF, the BAT-based BF-BOF, or natural gas–based DRI-EAF with a CCUS system and direct scrap-based steel produced using the EAF process.

From the modelling-based scenario analysis and stakeholder consultation, a detailed roadmap describing policy-, technology- and finance-related actions in the near, medium, and long term is presented to help propel the steel ecosystem in India towards deep decarbonisation. Some of the immediate actions towards greening the Indian steel industry include defining green steel and product standards, promoting the adoption of renewable energy and green hydrogen, and creating demonstration projects related to H_2 and CCUS to ensure the techno-economic feasibility of these routes along with building trust among investors, which is essential to scale the pilot projects to wider adoption.

The emerging carbon market in India will be essential for fast-tracking the green steel transition by reducing the viability gap between conventional and new low-carbon technology routes. Nonetheless, creating a market for low-carbon steel will be vital, especially in the near term when the green premium is substantial. None of this could be possible without green investment flowing into green hydrogen, renewable energy, CCUS, and green steelmaking routes. Financing mechanisms such as green bonds, sustainability-linked bonds, and concessional financing rates are necessary to keep the green steel transition on track. Even the evolution of the carbon economy through credit trading within the carbon market can help ensure the flow of money for green investment and the modernisation of fleets for the steel sector.

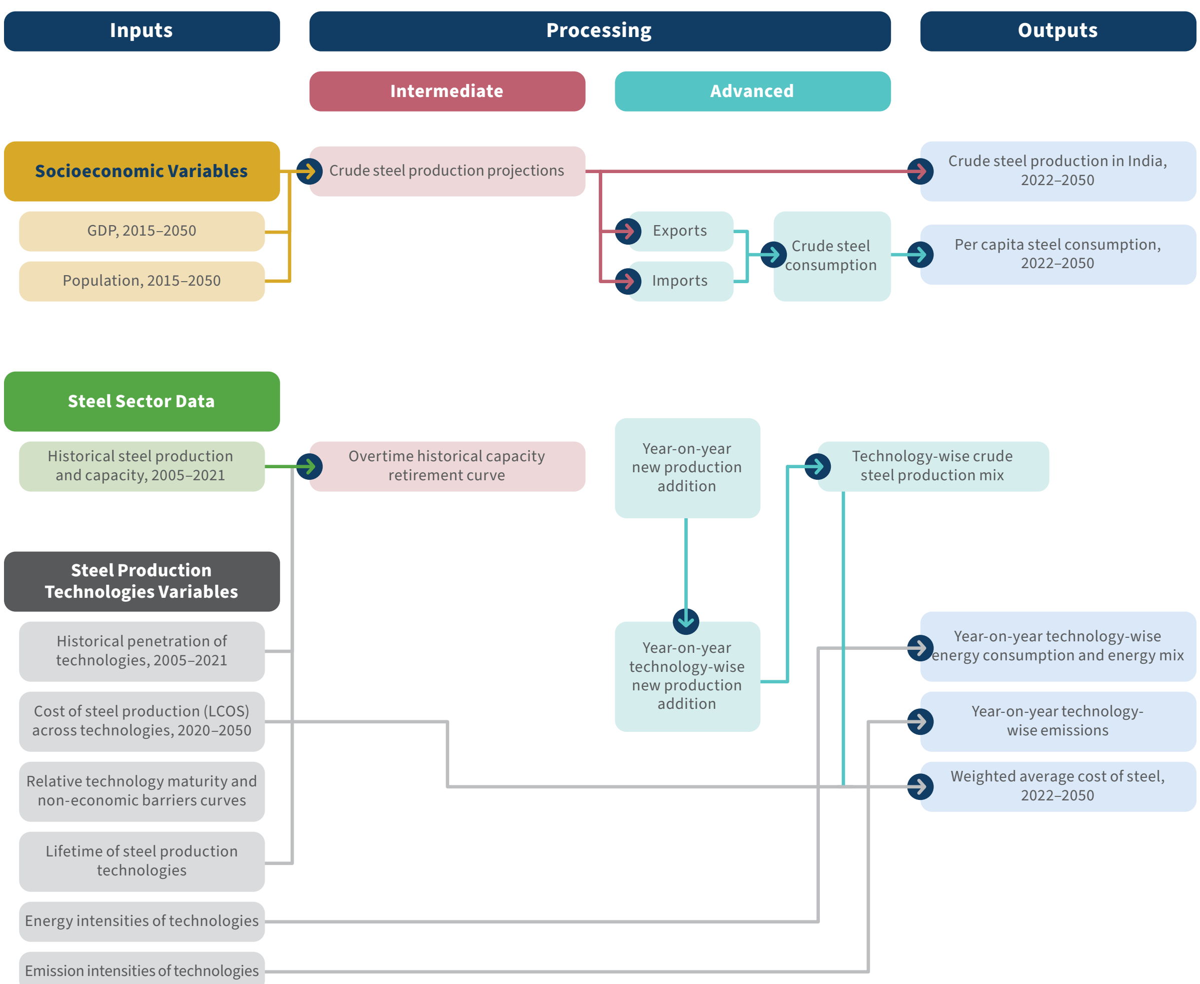
Like the plethora of challenges, the portfolio of solutions is wide, taking a systematic approach to each problem in the sector. However, to plan, innovate, and implement, cross-collaboration among relevant stakeholders is essential. Recently, there have been some multi-stakeholder initiatives to facilitate communications. However, to tackle hard-to-abate sectors like steel, fragmented efforts would need to converge and align with activities around manufacturers, consumers, financiers, researchers, and policymakers to accelerate the green steel transition in India.

Appendix

Methodology: Modelling Framework

This analysis was undertaken using RMI's in-house-developed India's Steel Techno-Economic Transition (I-STET) Model. The model framework is described in Exhibit A1. The I-STET model has a time horizon up to 2050 with year-on-year resolution. The geographic resolution is national, India. In the I-STET model, the steel demand in the economy is linked to economic growth (gross domestic product [GDP]) through sectoral income elasticity.

Exhibit A1 RMI's In-House-Developed India's Steel Techno-Economic Transition (I-STET) Model Framework



Source: RMI analysis

The model considers the lifetime of a steel plant. Based on the time horizon of historical steel production, the model considers retirement of production capacity over that lifetime. Therefore, decisions among different routes of steelmaking are limited to new production capacity driven by increasing demand and retirement of existing capacity. The theory behind this competition is inspired by real-life scenarios in which new investments fill in the lag between demand and supply.

The levelised cost of steel (LCOS) variable is a crucial determinant for any production route in the I-STET model. Within the model, there is an embedded LCOS model that covers 13 different steel production routes (see **Exhibit 2,** page 13). LCOS across production routes is a function of capital cost levelised annually and the operation and maintenance cost, comprising raw material cost, fuel cost, labour charges, and other maintenance requirements. Within each route of steelmaking, detailed process-wide material flow, material balance, and energy balance are prepared. Those balances make up the foundation of the operations and maintenance component of LCOS. Most of the assumptions around capital cost, fuel cost, raw material cost, material flows, and so on are considered to be India-specific based on plant-level information.

Endnotes

1. *India Third Biennial Update Report to the United Nations Framework Convention on Climate Change*, Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, 2021, **https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf**; and *Components of Gross Value Added at Basic Prices: Handbook of Statistics on Indian Economy, Reserve Bank of India*, 15 September 2022, **https://rbidocs.rbi.org.in/rdocs/Publications/PDFs/3T_15092022BC57E7EF72A24DC8818E62C0F4CC0FBE.PDF**.

2. "Metal Sector Can Play Major Role towards Self-Reliant India and US$ 5 Trillion Economy by 2024-25, Says Shri Faggan Singh Kulaste," PIB-Ministry of Steel, 20 May 2022, **https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1826975**.

3. *Climate Change and the Production of Iron and Steel, World Steel Association*, 2021, **https://worldsteel.org/wp-content/uploads/Climate-change-and-the-production-of-iron-and-steel.pdf**.

4. "COP26: What Is Net Zero Emissions Pledged by Many Countries Including India," *India Times*, 12 November 2021, **www.indiatimes.com/explainers/news/cop26-what-is-net-zero-emissions-pledged-by-many-countries-553541.html**.

5. "Tackling the Challenge of Decarbonizing Steelmaking," McKinsey & Company, 18 May 2021, **www.mckinsey.com/industries/metals-and-mining/our-insights/tackling-the-challenge-of-decarbonizing-steelmaking**.

6. Sharp Increase in Coking Coal Prices to Reduce Steel Spreads by Rs.4,000 per Tonne, CARE Ratings, 2021, **www.careratings.com/uploads/newsfiles/12082021114644_Sharp_increase_in_coking_coal_prices_to_reduce_steel_spreads_by_Rs_4000_per_tonne.pdf**.

7. "Opinion: Can the Indian Steel Industry Join the Hydrogen Revolution?", *ET Energy World*, December 25, 2020, **https://energy.economictimes.indiatimes.com/news/renewable/opinion-can-the-indian-steel-industry-join-the-hydrogen-revolution/79943802**.

8. Ibid.

9. "Steel Sector Looks to Increase Production, Enhance Raw Material Security in 2022," *The Economic Times*, December 28, 2021, **https://economictimes.indiatimes.com/industry/indl-goods/svs/steel/increasing-production-enhancing-raw-material-security-focus-areas-for-steel-sector-in-2022/articleshow/88537212.cms**.

10. Green Hydrogen Policy, Ministry of Power, Government of India, 2022, **https://powermin.gov.in/sites/default/files/Green_Hydrogen_Policy.pdf**.

11. "The Top 5: Steel Companies in India & Their Commitments to Reduce CO2 Emissions," *Saur Energy*, May 27, 2022, **https://www.saurenergy.com/solar-energy-blog/the-top-5-steel-companies-in-india-their-commitments-to-reduce-co2-emissions**.

12. "Decarbonizing Steel: How the Demand for Greener Steel Will Upend the Supply Chain," MarshMcLennan *(Brink News)*, February 9, 2022, **https://www.brinknews.com/decarbonizing-steel-how-the-demand-for-greener-steel-will-upend-the-supply-chain/**.

13. *Annual Report 2021-22*, Ministry of Steel, Government of India, 2022, **https://steel.gov.in/sites/default/files/Download_0.pdf**.

14. *Harnessing Green Hydrogen: Opportunities for Deep Decarbonisation in India*, NITI Aayog and RMI, 2022, **https://rmi.org/insight/harnessing-green-hydrogen/**.

15. Ibid.

16. *Net-Zero Steel: Sector Transition Strategy*, Mission Possible Partnership, Energy Transition Commission and RMI, 2021, **https://missionpossiblepartnership.org/wp-content/uploads/2021/10/MPP-Steel-Transition-Strategy-Oct-2021.pdf**.

17. "What Are the Factors that Affect the Price of your TMT Bars," MS Life, 13 March 2021, **https://mslife.com/what-are-the-factors-that-affect-the-price-of-your-tmt-bars/**.

18. "A Green Approach to Producing Steel," *Business Line*, 15 December 2021, **https://www.thehindubusinessline.com/opinion/a-green-approach-to-producing-steel/article37963099.ece**.

19. Yadav, Deepak, Ashish Guhan, and Tirtha Biswas, Greening Steel: Moving to Clean Steelmaking Using Hydrogen and Renewable Energy, New Delhi: Council on Energy, Environment and Water, 2021, **www.ceew.in/publications/decarbonising-steel-making-using-clean-hydrogen-and-renewable-energy-in-india**.

20. "Energy-Intensive Steel Industry Looks to Push Consumption, Reduce Emissions," Mongabay, 16 March 2022, **https://india.mongabay.com/2022/03/energy-intensive-steel-industry-looks-to-push-consumption-reduce-emissions/**.

21. *Annual Report 2021-22*, Ministry of Steel, 2022.

22. Ankur Malyan and Vaibhav Chaturvedi, *Carbon Capture, Utilisation and Storage (CCUS) in India: From a Cameo to Supporting Role in Nation's Low Carbon Story*, 2021.

23. "Most Carbon Capture & Utilisation Technologies May Be Counterproductive: Study," DownToEarth, 23 February 2022, **www.downtoearth.org.in/news/science-technology/most-carbon-capture-utilisation-technologies-may-be-counterproductive-study-81665**.

24. *Annual Report 2021-22*, Ministry of Steel, 2022; and "Energy-Intensive Steel Industry," 2022.

25. "Climate Group SteelZero," Climate Group and Responsible Steel, 2022, **www.theclimategroup.org/steelzero**.

26. "Vehicle Scrappage Policy 2021," Ministry of Road Transport and Highways, Government of India, PIB, 18 March 2021, **https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1705811**.

27. "Steel Mills: Financing and Loans," ESFC Investment Group, accessed 11 February 2023, **https://esfccompany.com/en/projects/industry-and-environment/steel-mills-financing-and-loans/**.

28. "HYBRIT: New Research Shows Hydrogen-Reduced Iron Has Superior Properties," HYBRIT Fossil-Free Steel, last modified 12 October 2022, **https://www.hybritdevelopment.se/en/hybrit-new-research-shows-hydrogen-reduced-iron-has-superior-properties/**.

29. "HYBRIT Demonstration," HYBRIT Fossil-Free Steel, accessed 11 February 2023, **www.hybritdevelopment.se/en/hybrit-demonstration/**.

30. "Distribution of Steel End-Usage Worldwide in 2019, by Sector," Statista, 2021, **www.statista.com/statistics/1107721/steel-usage-global-segment/**.

31. *Annual Report 2021-22*, Ministry of Steel, 2022.

32. "SteelZero Members," Climate Group and Responsible Steel, 2022, **www.theclimategroup.org/steelzero-members**.

33. Timo Gerres et al, *Green Steel Production: How G7 Countries Can Help Change the Global Landscape, Leadership Group for Industry Transition*, 2021, **www.industrytransition.org/insights/g7-green-steel-production/**.

34. "Recent Study Reveals More Than a Third of Global Consumers Are Willing to Pay More for Sustainability as Demand Grows for Environmentally-Friendly Alternatives," *Business Wire*, 2021, **https://www.businesswire.com/news/home/20211014005090/en/Recent-Study-Reveals-More-Than-a-Third-of-Global-Consumers-Are-Willing-to-Pay-More-for-Sustainability-as-Demand-Grows-for-Environmentally-Friendly-Alternatives**.

35. "Fact Sheet," Boston Metal, October 14 ESFC Investment Group, 2022, **www.bostonmetal.com/wp-content/uploads/2022/10/Boston-Metal-FactSheet-20221026.pdf**.

36. "Al Reyadah Project Details," School of Geosciences, University of Edinburgh, 18 January 2022, **https://www.geos.ed.ac.uk/sccs/project-info/622**.

37. "CCS: A Necessary Technology for Decarbonising the Steel Sector," Global CCS Institute, 17 June 2017, **www.globalccsinstitute.com/news-media/insights/ccs-a-necessary-technology-for-decarbonising-the-steel-sector/**.

38. "December 2021 Crude Steel Production and 2021 Global Crude Steel Production Totals," World Steel Association, 25 January 2022, **https://worldsteel.org/media-centre/press-releases/2022/december-2021-crude-steel-production-and-2021-global-totals/**.

39. Desheng Xu et al, *Consumption-Driven Carbon Emission Reduction Path and Simulation Research in Steel Industry: A Case Study of China*, Sustainability, 2022; 14(20):13693. **https://doi.org/10.3390/su142013693**.

40. "Can Scrap Steel Solve China's Climate Dilemma?," Sixth Tone, 9 November 2022, **www.sixthtone.com/news/1011563/can-scrap-steel-solve-chinas-climate-dilemma**.

41. "Perform, Achieve, Trade (PAT) Scheme," International Energy Agency (IEA), May 12, 2021, **www.iea.org/policies/1780-perform-achieve-trade-pat-scheme**.

42. "Reduction of Carbon Emissions from Steel Plants," Press Information Bureau and Ministry of Steel, Government of India, Dec 20, 2021, **https://pib.gov.in/Pressreleaseshare.aspx?PRID=1783511**.

Decarbonising the Indian Steel Industry: Roadmap towards a Green Steel Economy,
RMI, March 2023, **https://rmi.org/insight/decarbonising-the-indian-steel-industry.**

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