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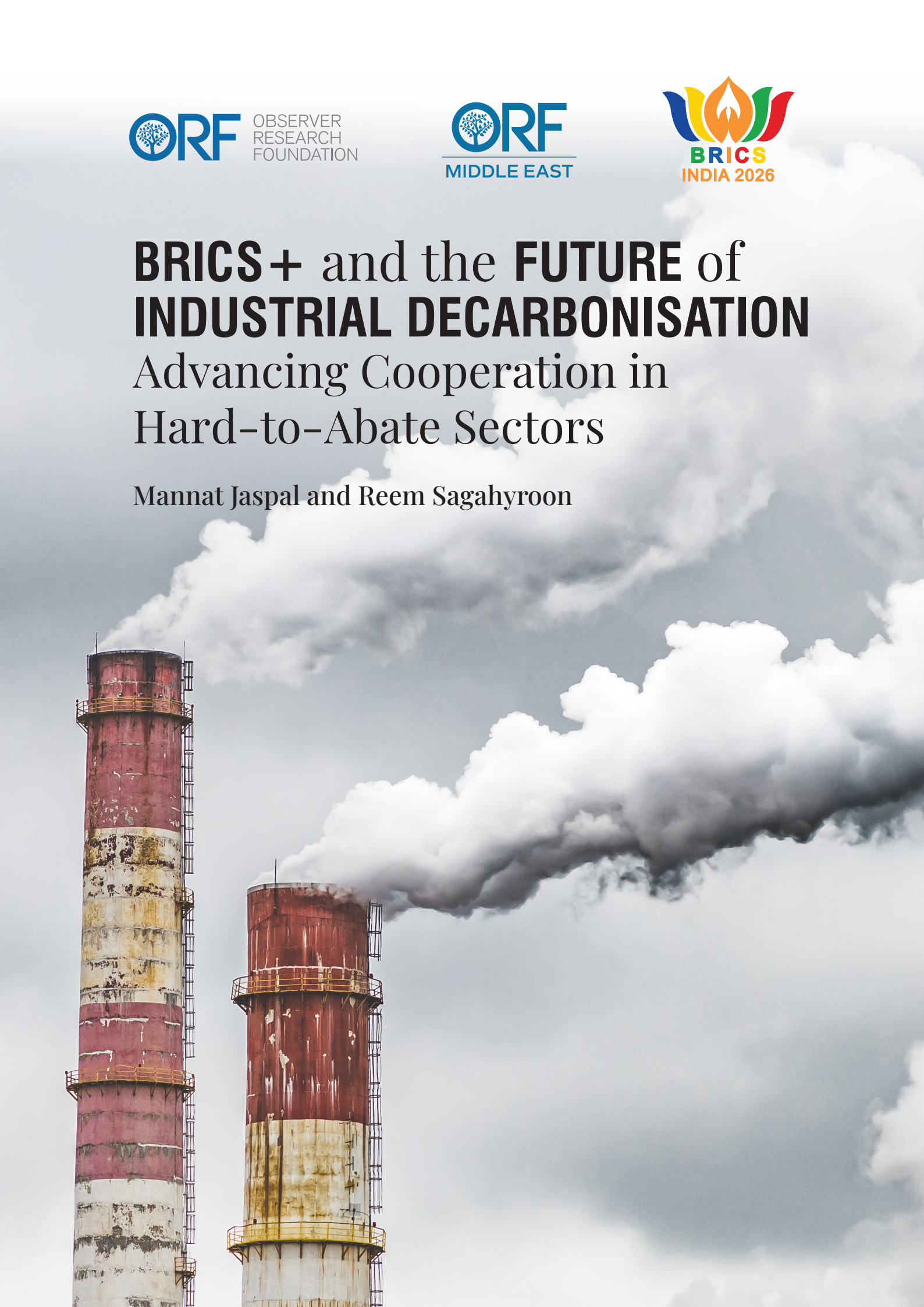
BRICS+ and the FUTURE of INDUSTRIAL DECARBONISATION

Advancing Cooperation in Hard-to-Abate Sectors

Mannat Jaspal and Reem Sagahyroon



BRICS+ and the FUTURE of INDUSTRIAL DECARBONISATION

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Chapter 1

Introduction

INDUSTRIALISATION HAS BEEN A POWERFUL ENGINE of economic growth, poverty reduction, and employment generation. At the same time, however, it is a significant contributor to global climate change. Industry accounts for almost one-fifth (over 21 percent) of the total global greenhouse gas (GHGs) emissions through direct emissions alone, and upwards of 31 percent factoring indirect emissions from electricity consumption.[1] Since 1990, industrial emissions have almost doubled, underscoring the imperative for pursuing strong industrial decarbonisation measures.

For emerging economies, industrial decarbonisation is a particularly massive challenge. Historically, advanced economies have developed at the back of unabated and environmentally unsustainable industrialisation, heavily relying on fossil fuels, which have substantially contributed to anthropogenic climate change. Today, developing countries face the dual imperative of economic development and sectoral decarbonisation. Unlike advanced economies which already have much of their industrial infrastructure built out, developing countries must invest in manufacturing, urban infrastructure, and energy systems aligned with low-carbon pathways.

This makes the BRICS+ countries central to the policy discourse on industrial decarbonisation. Comprising Brazil, Russia, India, China, South Africa, and the expanded membership of Egypt, Ethiopia, Indonesia, Iran, Saudi Arabia, and the United Arab Emirates (UAE), the bloc brings together major industrial producers, energy exporters and importers, resource-rich economies, and emerging manufacturing centres. These countries occupy an important position in the global value chains (GVCs) of manufacturing and industrial commodities, and decisions taken in these countries regarding investment in industrial technologies, energy systems, manufacturing capabilities, and resource use will have strong implications well beyond the grouping.

The recent crises in the Middle East, with disruptions of energy flows at the Strait of Hormuz and Bab-Al Mandab, have further reinforced the vulnerabilities associated with concentrated energy supply chains and exposure to geopolitical shocks. For energy importing countries, reducing reliance on unreliable energy inflows and expanding access to low-carbon, domestically produced electricity can help reduce exposure to volatile fuel prices and external supply disruptions. For energy exporting countries, decarbonisations efforts are a measure to remain industrially competitive and diverse as global markets evolve. For BRICS+ countries, therefore, industrial decarbonisation is increasingly intertwined with questions of energy security, economic and industrial resilience, technological competitiveness, and connectivity to international markets.

Trade is another dimension to this transition. The European Union's Carbon Border Adjustment Mechanism (CBAM) is a domestic industrial policy that will penalise products entering its borders on the basis of emission intensity. At the time of writing this report, six sectors were covered by the CBAM—aluminium, cement, electricity, fertiliser, hydrogen, and iron and steel—and its coverage is expected to expand over time.[2] Specifically on tariff oriented barriers, the EU also imposed new steel tariff-rate quotas (TRQs) in July this year, with a specific quota for each of 26 different steel product categories, with almost 50 percent out-of-quota duty in some cases if countries exceed their quarterly ceiling for imports.[3]

For BRICS+ economies, these developments present both risks and opportunities. Carbon-intensive production could face rising compliance costs and barriers to market access, while early investment in low-emission technologies could strengthen competitiveness, attract investment, and create new industrial capabilities.

Recognising these challenges, the BRICS+ have prioritised decarbonisation and energy transition in their broader development and national strategies. The bloc is responsible for over 40 percent of global carbon dioxide (CO_2) emissions. The scale of the bloc's industrial footprint is particularly significant across sectors such as mining, metals, chemicals, and other energy-intensive industries, making industrial decarbonisation an important component of its wider climate and energy-transition agenda.

Industrial decarbonisation differs fundamentally from power-sector decarbonisation. While expanding renewable electricity can reduce emissions associated with industrial energy consumption, it cannot, on its own, eliminate emissions arising from chemical processes, high-temperature heat requirements, or the production of materials such as cement and primary metals. Effective industrial decarbonisation must therefore address both energy-related and process-related emissions through a combination of electrification, low-carbon fuels, material substitution, recycling, alternative production routes, and, where appropriate, carbon capture technologies.

The New Delhi Declaration highlights the members' commitment to advancing industrialisation in an environmentally sustainable manner.[4] It also reaffirms the Partnership on the New Industrial Revolution (PartNIR) as a key platform for strengthening industrial cooperation, technology exchange, innovation, and engagement across seven specialised BRICS industrial working groups: Chemical Industry; Mining and Metals; Digital Transformation of Industry; Small and Medium Enterprises (SMEs); Intelligent Manufacturing and Robotics; Photovoltaic Industry and Medical Devices and Pharmaceuticals. The BRICS Centre for Industrial Competencies, established in cooperation with UNIDO, also provides a platform for technology exchange and the adoption of advanced industrial production technologies.

Although fossil fuels will remain integral to BRICS economies, as acknowledged in the 11th BRICS Energy Ministerial Communiqué,[5] there is an equally strong push to expand renewable energy deployment, strengthen energy-efficiency measures, and accelerate cooperation on emerging low-carbon technologies. Some of the areas identified for collaboration include: zero- and low-emission hydrogen and its derivatives, renewable energy, energy storage, carbon capture, utilisation and storage (CCUS), and other abatement technologies. All of these represent important levers for reducing industrial emissions. BRICS members have also encouraged cooperation on interoperable standards and certification frameworks for low-emission hydrogen, alongside the development of a BRICS Joint Report on Hydrogen Value Chains. These priorities are increasingly being translated into sector-specific cooperation mechanisms.

Alongside these sectoral mechanisms, cooperation is also expanding in the areas of resource efficiency and circularity. The BRICS Environment Working Group has called for stronger collaboration on circular economy approaches through technology transfer, investment, research and innovation, capacity building, and knowledge exchange, while encouraging greater use of BRICS-led knowledge networks such as the BRICS Resource Efficiency and Circular Economy Dialogue.[6] These initiatives are particularly relevant to industrial decarbonisation given the role of material efficiency, recycling, waste reduction, and secondary resource use in lowering emissions from energy- and resource-intensive sectors.

While these efforts are commendable, it is important to acknowledge that industrial policies, resource endowments, technological capabilities, and development priorities vary across the BRICS+ countries. For instance, India and China possess large and diverse manufacturing bases while others like Russia and the Gulf countries have industrial systems more closely tied to hydrocarbons and energy-intensive industries. Any cooperation proposition must therefore consider these differences, making a uniform decarbonisation pathway neither practical nor desirable. Instead, cooperation must build on national strengths, recognise different development trajectories, and identify areas where shared technologies, financing mechanisms, standards, and industrial policies can accelerate progress.

A just and inclusive transition must remain central to this agenda. Small and medium-sized enterprises (SMEs) are important participants in industrial value chains, and face constraints in accessing affordable finance, technical expertise, modern equipment, and reliable emissions data. SMEs must be central to the industrial planning process as the sector accounts for almost 90 percent of businesses and over half of employment.[7]

Against this backdrop, this report examines industrial decarbonisation across BRICS+ countries with a particular focus on four hard-to-abate sectors: iron and steel, cement, aluminium, and chemicals. These sectors have been selected given their substantial contribution to industrial emissions. Collectively, iron and steel, cement, and the chemical sectors account for almost 71 percent of industrial emissions.[8] While the scope is not intended to provide an exhaustive assessment of the industrial emissions profile of BRICS+ economies, these four sectors offer a strategic lens through which to examine decarbonisation opportunities in industries that underpin infrastructure development, manufacturing, energy-transition technologies, and the expansion of global supply chains. The objective is to delineate the decarbonisation challenges in each sector, identify best practices in terms of transferable policies and technologies across different national contexts. The report identifies opportunities for BRICS+ cooperation in technology development and deployment, industrial innovation, financing, standards, circularity, and capacity building.

Table 1: Overview of Industrial Energy and Emissions Profiles Across BRICS+ Economies

Country (net zero target)	Industry's Share Of Total Energy-Related CO_2 Emissions (2024)[9]	Industry's Share of Final Energy Consumption (2024)[10]	Primary Electricity Sources (2024)*[11]	Sectoral Distribution of Process-Related Emissions in Industry	Sectoral Distribution of Fuel-Related Emissions in Industry	Industrial Decarbonisation Policies and National Initiatives
Brazil (2050)	21%	33%	***Hydropower*** 51.7% ***Wind*** 15.0% ***Solar*** 11.4% ***Biofuels*** 8.5% ***Natural Gas*** 7.6%	***2022***[12] • 51% Metals (of which 92% iron & steel) • 32% Minerals (of which 75% cement & 18% lime) • 9% Chemicals (of which 95% petrochemicals & carbon black)	***2022***[13] • 25% Non-metallic minerals • 18% Chemicals • 12% Iron & steel	• National Industrial Decarbonisation Strategy (ENDI) • Industry Sector Mitigation Plan (PSMI) • Industry Decarbonisation Program (IDP) (in progress) • Brazilian Sustainable Taxonomy • National Low-Carbon Hydrogen Policy (Law No. 14,948/2024) • Brazilian Emissions Trading System (SBCE) • Nova Indústria Brasil

Country (net zero target)	Industry's Share Of Total Energy-Related CO_2 Emissions (2024)[9]	Industry's Share of Final Energy Consumption (2024)[10]	Primary Electricity Sources (2024)*[11]	Sectoral Distribution of Process-Related Emissions in Industry	Sectoral Distribution of Fuel-Related Emissions in Industry	Industrial Decarbonisation Policies and National Initiatives
Russia (2060)	16%	29%	***Natural gas*** 45.3% ***Coal*** 18.2% ***Nuclear*** 17.5% ***Hydropower*** 17.3%	***2024***[14] • 44% Metallurgy (of which 89% iron and steel sector and 7% aluminium sector) • 26% Chemicals (of which 44% ammonia production and 20% petro chemicals) • 17.5% Mineral products (of which 63% cement and 21% lime)	***2024***[15]** • 27% Iron and steel • 14% Chemicals • 18% Non-metallic minerals (such as cement and lime) • 32% Others	• Strategy of Socio-Economic Development of the Russian Federation with Low Greenhouse Gas Emissions to 2050 • Federal Law No. 296-FZ on Limiting GHG Emissions • Project-Based Carbon Credit Market (PCCM) • Federal Law No. 261-FZ on Energy Efficiency
India (2070)	24%	40%	***Coal*** 72.3% ***Hydropower*** 7.7% ***Solar*** 7.1% ***Wind*** 4.6% ***Natural gas*** 2.9%	***2022***[16] • 58% Minerals (of which 86% cement and 13% lime) • 22% Chemicals (of which 41% petrochemicals & carbon black and 18% ammonia) • 9% Metals (of which 62% aluminium and 36% ferroalloys)***	***2022***[17] • 37% Iron & steel • 12% Non-metallic minerals (such as cement and lime) • Chemicals 1.2% • Other 48%	• Carbon Credit Trading Scheme (CCTS) • National Green Hydrogen Mission • Perform, Achieve and Trade (PAT) Scheme • National Steel Policy 2017 • Green Steel Taxonomy

Country (net zero target)	Industry's Share Of Total Energy-Related CO_2 Emissions (2024)[9]	Industry's Share of Final Energy Consumption (2024)[10]	Primary Electricity Sources (2024)*[11]	Sectoral Distribution of Process-Related Emissions in Industry	Sectoral Distribution of Fuel-Related Emissions in Industry	Industrial Decarbonisation Policies and National Initiatives
China (2060)	24%	48%	***Coal*** 58.6% ***Hydropower*** 13.9% ***Wind*** 9.7% ***Solar*** 8.2% ***Nuclear*** 4.4% ***Biofuels*** 2.2%	***2020***[18] • 50% Minerals (such as cement and lime • 22.5% Chemicals • 9.8% Metals (such as aluminium and iron and steel)	-	• Industrial Green and Low-Carbon Development Plan (2026–2030) • Action Plan for Carbon Peaking During the 15th Five-Year Plan Period (2026–2030) • Three-Year Action Plan for Energy Conservation and Carbon Reduction in Key Industries (2026–2028) • National Emissions Trading System (ETS) • Zero-Carbon Industrial Parks and Factories Programme • Hydrogen Demonstration Programme (2026–2030)

Country (net zero target)	Industry's Share Of Total Energy-Related CO_2 Emissions (2024)[9]	Industry's Share of Final Energy Consumption (2024)[10]	Primary Electricity Sources (2024)*[11]	Sectoral Distribution of Process-Related Emissions in Industry	Sectoral Distribution of Fuel-Related Emissions in Industry	Industrial Decarbonisation Policies and National Initiatives
South Africa (2050)	12%	38%	***Coal*** 85.0% ***Wind*** 4.7% ***Nuclear*** 3.5% ***Hydropower*** 2.6% ***Solar*** 2.3%	***2022***[19] • 51% Metals (of which 51% iron alloys and 40% iron & steel; 8% aluminium) • 19.8% Minerals (of which 83% cement and 11% lime) • 5.7% Chemicals	***2022***[20] • 6% Iron & steel • Majority (~90%) reported under other/non-specified industry	• Industrial Development Strategy (IDS) 2026 • Carbon Tax Act – Phase 2 (2026–2030) • Just Energy Transition Investment Plan (JET-IP) • Carbon Border Adjustment Readiness Initiatives
Indonesia (2060)	17%	40%	***Coal*** 70.5% ***Natural gas*** 12.5% ***Hydro*** 5.6% ***Biofuels*** 5.4% ***Geothermal*** 3.5% ***Oil*** 2.1%	***2022***[21] • 55% Minerals (of which 92% cement production) • 19% Metals (of which 93% iron and steel and 5% aluminium) • 18% Chemicals (of which 66% ammonia and 25% petrochemicals and carbon black)	-	• Industrial Decarbonisation Roadmap • CCUS Regulatory Framework (Presidential Regulation 14/2024) • National Hydrogen Roadmap 2025–2060 • Net Zero Industrial Precincts (NZIP) Programme • Indonesia Taxonomy for Sustainable Finance (TKBI) Version 3

Country (net zero target)	Industry's Share Of Total Energy-Related CO_2 Emissions (2024)[9]	Industry's Share of Final Energy Consumption (2024)[10]	Primary Electricity Sources (2024)*[11]	Sectoral Distribution of Process-Related Emissions in Industry	Sectoral Distribution of Fuel-Related Emissions in Industry	Industrial Decarbonisation Policies and National Initiatives
UAE (2050)	35%	43%	***Natural gas*** 69.6% ***Nuclear*** 21.8% ***Solar PV*** 6.9% ***Solar thermal*** 1.2%	***2022***[22] • 38% Minerals (99% cement) • 26% Metals (of which 72% aluminium and 28% iron and steel) • 18% Chemicals (85% petrochemicals and carbon black and 15% ammonia)	***2022***[23] • 63% Non-ferrous metals (mainly aluminium smelting) • 28% Non-metallic minerals • 9% Iron & steel	• Industrial Decarbonisation Roadmap • Operation 300bn • National Hydrogen Strategy 2050 • National Energy and Water Demand Management Programme 2050 • Circular Economy Policy
Egypt	18%	27%	***Natural gas*** 76.9% ***Oil*** 10.0% ***Hydro*** 6.6% ***Solar PV*** 3.2% ***Wind*** 3.2%	***2022***[24] • 50% Minerals (of which 96% from cement) • 15% Chemicals (of which 67% from ammonia and 22% petrochemicals & carbon black) • 19% Metals (of which 50% iron & steel and 47% aluminium)	-	• National Low-Carbon Hydrogen Strategy • National Council for Green Hydrogen and its Derivatives • Green Sustainable Industry (GSI) Program • Industrial Energy Efficiency Programme
Iran	18%	27%	***Natural gas*** 79.2% ***Oil*** 14.3% ***Hydro*** 4.3% ***Nuclear*** 1.6%	-	-	• National Climate Change Management Programme (2025) • Seventh Five-Year Development Plan (2023–2027) • National Energy Productivity and Efficiency Measures

Country (net zero target)	Industry's Share Of Total Energy-Related CO_2 Emissions (2024)[9]	Industry's Share of Final Energy Consumption (2024)[10]	Primary Electricity Sources (2024)*[11]	Sectoral Distribution of Process-Related Emissions in Industry	Sectoral Distribution of Fuel-Related Emissions in Industry	Industrial Decarbonisation Policies and National Initiatives
Ethiopia (2050)	42%	5%	***Hydro*** 97.1% ***Wind*** 2.7%	***2020***[25] • Minerals dominate (cement responsible for 94% of industry sector emissions	-	• Climate-Resilient Green Economy (CRGE) Strategy • Energy Efficiency Strategy for Industries, Buildings and Appliances • Long-Term Low-Emission Development Strategy (LT-LEDS 2050) • Sustainable Industrial Parks Programme
Saudi Arabia (2060)	14%	19%	***Natural gas*** 57.7% ***Oil*** 40.8% ***Solar PV*** 1.1%	***2021***[26] • 35.6% Minerals (of which 94% from cement); • 45% Chemicals (of which 80% petrochemicals & carbon black; 20% ammonia); • 17.8% Metals (of which 90% iron & steel and 8.5% aluminium)	***2021***[27] • 36% Chemicals • 21% non-metallic minerals (such as cement and lime) • 5.4% Iron & steel • 38% non-specified industry	• National Strategy for Industry (2022) • Saudi Energy Efficiency Centre (SEEC) Industrial Programme • Industrial Sector Competitiveness Programme • Circular Carbon Economy Framework • Saudi Green Initiative

Source: Authors' own, using various sources as cited.

** Data for Brazil are from 2025.*

***Russia's Common Reporting Table (CRT) lists energy-related emissions from non-ferrous sector (such as aluminum) as 'Included Elsewhere'*

**** India's Biennial Transparency Report included emissions occurring from the iron and steel IPPU boundary (i.e. process emissions) within the energy sector emissions.*

Chapter 2

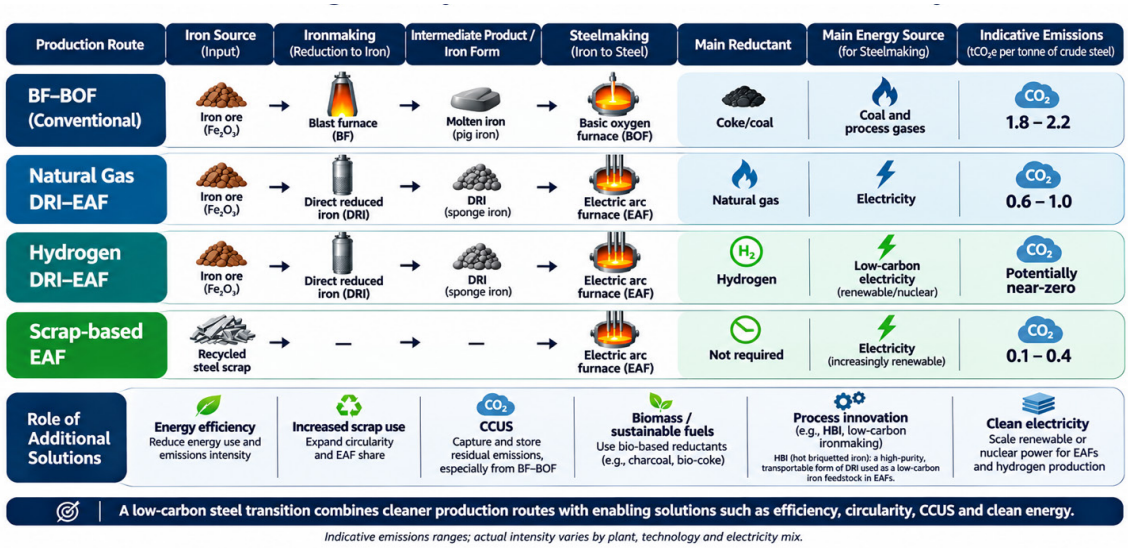
Decarbonising Hard-to-Abate Sectors

2.1 Iron and Steel

2.1.1 Why is the Iron and Steel sector difficult to decarbonise?

The iron and steel industry is responsible for 7-9 percent of GHG emissions.[28] This is primarily due to the heavy reliance on coal-based steelmaking. There are two types of steel production routes, each with different CO_2 footprints. The first is the integrated Blast Furnace – basic oxygen furnace (BF-BOF) which makes up about 70 percent of global steel production today;[29] the second is the Electric Arc Furnace (EAF) method.

Figure 1: Steel Production Routes and Their Reductant and Energy Requirements



Source: Authors' own, designed using ChatGPT.

In the traditional BF-BOF manufacturing process, the mined iron ore ($Fe2O3$) is mixed with coke (purified coal used as fuel) and limestone and fed into a blast furnace, producing molten iron (also called pig iron). The coke acts as a reducing agent (removes oxygen from the iron ore) and allows the ore to burn at very high temperatures while the limestone acts as a cleaning flux removing the impurities into a slag. The molten iron is then subjected to high-purity oxygen in the BOF which generates substantial process heat. This highly emission-intensive process converts molten iron into raw steel discounting the excess carbon and other impurities.[30]

In the alternative Electric Arc Furnace (EAF) route, there are three approaches that can be followed: First, the coke is replaced with natural gas (transition fuel) and potentially with hydrogen as a reducing agent to convert the iron ore into solid iron, also called direct reduced iron (DRI). The DRI removes the oxygen without melting the ore. The electricity provide the heat source and powers the EAF which melts the DRI into steel.[31]

DRI is relatively porous and reactive, which makes long-distance transportation more complicated. If the objective is not to use the DRI directly (say, due to high electricity costs or poor access to renewable energy), it can be compressed into dense briquettes called Hot Briquetted Iron (HBI) and exported to regions for steelmaking.[32] The importing country will put HBI into a localised EAF along with scrap to produce low carbon steel. Finally, the third option is to use recycled scrap and melt it into liquid steel using giant graphite electrodes in the furnace capable of generating extreme heat. Although scrap-based EAF is less emission-intensive than BF-BOF and could be powered completely by renewable energy, there is likely not sufficient scrap to meet global demand.

Eco-friendly steel making will have to use a combination of solutions – Electric Arc Furnace using scrap, direct reduced iron (DRI)/ hot briquetted iron (HBI) produced using natural gas and eventually hydrogen, and powered by green energy and supported by carbon capture, utilisation, and storage (CCUS).

The primary challenges in decarbonising the Iron and Steel sector are:

1. High Capital Costs and Uncertain Economics

The techno-economic limitations and high associated costs pertaining to new furnaces, hydrogen infrastructure, renewable power, grids, storage and transport pose the most significant challenge. For hydrogen, specifically, cost depends on cheap renewable electricity, electrolysers, storage and transport. According to an IEA report, hydrogen direct reduced iron electric arc furnace (H2 DRI-EAF) plants that use 100 percent hydrogen blends are estimated to cost 50-140 percent more than BF-BOF plants today, the price varying based on the region.[33] Such high costs inevitably constrain deployments, and given steel's pervasive applicability, consumers are unlikely to absorb the associated green premium.

2. Insufficient Low-Carbon Electricity and Grids

Electricity, preferably sourced from non-fossil source, is critical at both the reduction stage/ iron making (when dealing with iron ore and not scrap) as well as at the steelmaking stage. EAFs, hydrogen production and electrified industrial processes increase electricity demand, and without a strong and reliable production, distribution and transmission system, grid infrastructure and storage, access, affordability and reliability of RTC clean energy becomes industrial-policy issues. Besides, this electricity should not cannibalise from existing and future residential and commercial demand centres.

3. Lack of Common Standards and Markets for "Green Steel"

While some progress has been made to develop global interoperability between leading existing definitions, standards and emissions measurement methodologies for near-zero and low-emissions steel production, clarity and applicability remains weak.

4. Limited Availability of High-Quality Scrap

Scrap-EAF steel production method is inevitably limited in scope given that the supply is constrained, particularly in fast-growing or developing economies where steel stocks have not yet accumulated. DRI and HBI will act as important complementary agents to scrap in this regard.

5. Existing BF-BOF Assets and Stranded-Asset Risk

Steel plants can operate for decades. Replacing them prematurely involves huge capital losses, while continuing to operate them creates emissions lock-in. Developing economies face a particularly difficult balance between decarbonisation and industrial growth.

2.1.2 Steel Decarbonisation Pathways in Major BRICS+ Producing Economies

Table 2: Overview of Top BRICS+ Steel Producers

Country	Share of Global Production Volume *million tonnes* (ranking)[34] (2025)	Profile[35,36]	National Policies/ Targets	Corporate Action
Russia	68 (5th globally)	• Primarily BOF route (64%) followed by EAF (34%) • CO2e Intensity between 2.1-2.2 t CO2e/t crude steel	• Strategy for the Development of the Metallurgical Industry to 2030 • Green taxonomy criteria for steel producers under Government Decree No. 373 • Low GHG Emission Socio-Economic Development Strategy to 2050 lists metallurgy specific measures • Federal Law No. 296-FZ On Limiting Greenhouse Gas Emissions requires metallurgy sector reporting of CO2 emissions	**Key Players:** NLMK Group (Novolipetsk Steel) Severstal; EVRAZ; MMK (Magnitogorsk Iron and Steel Works); Metalloinvest **Key Measures:** • ***Fuel substitution***: Metalloinvest developing an HBI plant designed for up to 100% hydrogen reducing gas and an adjacent electric steelmaking shop [37] • ***Waste-gas reuse:*** NLMK plant will capture BOF gas originally flared to generate electricity[38] • ***Sustainable finance***: Mettaloinvest utilised climate-transition bonds to support the decarbonisation transition programme.[39]
India	165 (2nd globally)	• Primarily EAF route (58%) followed by BOF (42%) • CO_2e Intensity between 2.45-2.5 t CO_2e/t crude steel	• Hydrogen strategy allocates $54 million USD for low carbon steel projects • Taxonomy for Green Steel for India defining green steel requirements • Ministry of Steel released 'Greening the Steel Sector in India: Roadmap and Action Plan' • Draft emission reduction targets for the iron and steel sector under the CCTS • Steel Scrap Recycling Policy	**Key players:** Tata Steel; JSW Steel; SAIL; Jindal Steel; Jindal Stainless; RINL; GPIL **Key measures:** • ***Green hydrogen***: JSW Steel commissioned a 25 MW green-hydrogen electrolyser for steelmaking; Jindal Stainless operates a green hydrogen plant for stainless production[40] • ***CCUS***: JSW Steel operates CCU at demonstration scale and is evaluating wider CCUS deployment for BF-BOF production

Country	Share of Global Production Volume *million tonnes* (ranking)[34] (2025)	Profile[35,36]	National Policies/ Targets	Corporate Action
China	961 (1st globally)	• BOF-dominated route (89%) followed by EAF (10%) • CO_2e Intensity between 2.5-2.6 t CO_2e/t crude steel	• Implementation Plan for Carbon Peaking in the Iron and Steel Industry • Steel Industry Energy Conservation and Carbon Reduction Action Plan (2024-2025) • Sector prioritized in the 15th five-year plan including increase the organised import of high-quality scrap by 2030 • EAF share of crude steel is targeted at above 20 percent by 2030 • Steel sector is among the industries targeted in the Notice on Three-year action plan to tackle energy conservation and carbon reduction • Metallurgy sector targeted in the implementation Plan for Accelerating Clean and Low-Carbon Hydrogen Application in the Industrial Sector • Steel sector included in the National ETS	**Key players:** Baowu Steel Group; Ansteel Group; HBIS Group (Hebei Iron and Steel Group); Jiangsu Shagang Group **Key measures:** • ***Waste gas reuse***: Baowu Steel Operates a hydrogen-based DRI plant derived from refined coke oven gas with a target of fully utilizing green power and green hydrogen by 2035[41] • ***Scrap use***: Baosteel tested up to 50% scrap charging in the BF route and plans a 2.3 Mt/ year scrap-based EAF by 2030 • ***Green hydrogen:*** HBIS Group 1.2 Mt hydrogen metallurgy demonstration project in stable continuous production of green DRI[42]

Country	Share of Global Production Volume *million tonnes* (ranking)[34] (2025)	Profile[35,36]	National Policies/ Targets	Corporate Action
Brazil	33 (9th globally)	• BF-BOF dominated (76 percent) followed by EAF (23%) • 11% of BF-BOF utilize charcoal from planted forests instead of coal[43] • CO_2e Intensity of approx. 2 t CO_2e/t crude steel	• Plano Clima Sectoral Mitigation Plan for Industry addresses the steel sector with named technological measures and timelines. • Sustainable Taxonomy of Brazil defines qualifying low-carbon steel activities • Brazil Investment Platform (BIP) qualification parameters create a "low-carbon steel" subsector • Legal framework for low-carbon H2 production encourages application in sectors including steel	**Key players:** ArcelorMittal Brasil; Gerdau; Ternium; CSN; Usiminas; AVB; Brazil Iron; Vale **Key measures:** • ***Fuel switching:*** approximately 13% of Brazil's total planted forest area is dedicated to steel[44]; Aço Verde Brasil built the first carbon-neutral integrated steel plant globally, using biochar derived from planted forests[45] • ***Scrap use:*** Gerdau, the largest Brazilian steelmaker produces nearly 70% of its steel production from scrap[46]. • ***Green hydrogen:*** As of 2024, Vale is in partnership with GEP to develop feasibility studies for the installation of a green hydrogen production units in Brazil[47]
Iran	32 (10th globally)	• EAF-dominated route (92%) followed by BOF (8%) • About 90% of steel production is through natural gas-based DRI[48]	• Law on Modifying Energy Consumption Patterns (2011) mandated halving national energy intensity with industrial standards and incentives • Targeted Subsidy Reform (2010) raised industrial energy prices • IMIDRO (Mines and Mining Industries Development and Renovation Organization) signed an MoU for a "Feasibility Study of Green Steel Production"	**Key players:** Mobarakeh Steel Company; Khouzestan Steel Company (KhSC), and Esfahan Steel Company (ESCO) **Key measures:** • Mobarakeh Steel Company targets a 30 percent cut in carbon emissions by 2032 and is running a hydrogen (gray) DRI pilot [49]

Source: Authors' own, using various sources as cited.

2.2 Cement

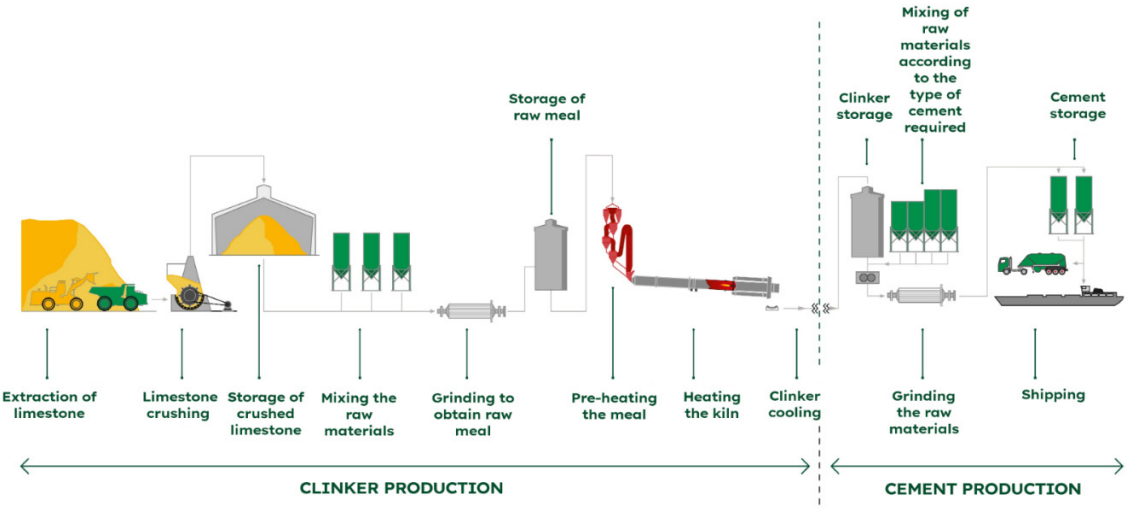
2.2.1 Why is the Cement sector difficult to decarbonise?

Cement production is also characterised by both heat- and process-related emissions. However, unlike steelmaking, in which coke can be replaced in both the process and energy stages, in cement production, even if the entire plant is powered by renewable electricity, a large share of the emissions emerge from the process of producing clinker.

To understand this challenge, it is important to first understand the cement production process. Limestone, the primary raw material, is heated at very high temperatures in a kiln to produce clinker which is then grounded with gypsum and other materials to produce cement. The emissions arise from both energy (to produce heat) and the process itself of breaking limestone. Even if the kiln was powered entirely by clean energy, CO_2 is released when the limestone undergoes calcination. While fossil fuel combustion for thermal energy, electricity generation, and mobility contributes 40-45 percent of GHG emissions in the entire value chain, the primary source of GHG emissions can be attributed to calcination, in which limestone is heated at very high temperature to convert it to Calcium Oxide (CaO), a key ingredient in cement.[50]

Limestone + heat → clinker → grinding + other materials → Cement

Figure 2: Clinker and Cement Production Route



Source: Heidelberg Materials[51]

Decarbonising the energy component nevertheless offers tremendous potential. Fossil fuels traditionally used such as coal and petroleum coke to generate heat the kiln can be substituted with biomass and waste derived fuels. Other interventions include improving thermal efficiency, recovering waste heat, electrifying industrial heat and integrating renewable electricity. In the longer term, advanced electric kilns and low-carbon hydrogen may also offer

alternative pathways for supplying process heat.[52] However, these interventions primarily address energy-related emissions, they do not eliminate the CO_2 inherently released through limestone calcination.

Decarbonisation efforts to mitigate process-related emissions include reducing the clinker-to-cement ratio in concrete by incorporating supplementary cementitious materials (SCM), such as fly ash, granulated blast furnace slag and calcined clay, while maintaining performance, durability, and long-term strength.[53] CCUS will become essential to manage residual emissions. The availability and suitability of these alternatives, however, vary across markets and production systems.

The primary challenges in decarbonising the cement sector are:

1. Process Emissions Cannot Be Electrified

Unlike combustion-related emissions, there is no direct and complete alternative to limestone calcination process through renewable electricity or fuel switching. There is no method currently deployed that can fully replace conventional limestone-based clinker production while maintaining the required material properties.

2. Electrification is Technically Difficult

Cement kilns operate at extremely high temperatures, with clinker formation requiring temperatures of approximately 1,450°C.[54] Electrification will require providing electricity at very high temperature reliably, continuously and economically. While electric heating technologies are advancing, their deployment in the cement sector remains limited. Furthermore, integrating large-scale industrial electricity loads into existing grids can increase the pressure on transmission and distribution grids.

3. Availability of Substitutes (Clinker and Alternative Fuels)

The availability of suitable clinker substitutes is a significant bottleneck for cement production. For instance, fly ash and ground granulated blast furnace slag (GGBS) are produced as byproducts of coal-fired power generation and conventional steelmaking.[55] As the steel sector decarbonises, their availability may also decline. Limestone is a cost-effective filler but has limited reactivity. while calcinated clay is widely available, reactive, low-carbon, however, requires optimisation in mix design.[56] Just as scrap is a constraint for steel making, suitable clinker substitutes can be a constraint for producing low carbon cement. At the same time, alternative fuels such as waste and biomass are constrained by availability, transport and consistency; and hydrogen is a very expensive alternative as of today.

4. CCUS is Expensive and Infrastructure-Intensive

Given the difficulty to removing emissions from the cement sector, CCUS will have to address the residual process emissions. However, reliance on CCUS also presents a risk of moral hazard which may delay the investments in emission reduction and abatement. CCUS should complement rather than substitute efforts in clinker substitution, energy efficiency, fuel switching and electrification. These efforts are compounded by the economics of the cement industry, as a price sensitive product, cement offers producers limited scope to pass the additional cost of low-carbon cement to consumers.

2.2.2 Cement Decarbonisation Pathways in Major BRICS+ Producing Economies

Table 3: Overview of Top BRICS+ Cement Producers

Country	2024 Share of global Production Volume *million tonnes* (ranking)[57]	Profile	National Policies/ Targets	Corporate Action
China	1900 (1st globally)	• Coal dominates cement production[58] • Emission intensity of about 0.82tCO_2/t of cement[59]	• Action Plan for Energy Saving and Carbon Reduction in the Cement Industry (2024-2025) & provides goals for directional goals for 2030 • Energy Efficiency Benchmark and Standard Levels for Cement • Cement sector included in the National ETS	**Key players:** CNBM (China National Building Material); Anhui Conch Cement; Huaxin Cement; China Resources Building Materials Technology (CRBMT); BBMG/ Jidong Cement **Key measures:** • ***CCUS*:** CNBM commissioned an oxy-fuel combustion coupled with CCUS in Qingzhou. The largest in the global cement industry[60] • ***Fuel Substitution*:** Anhui Conch achieved 26.5% substitution using agricultural residues and waste-derived fuels[61]

Country	2024 Share of global Production Volume *million tonnes* (ranking)[57]	Profile	National Policies/ Targets	Corporate Action
India	450 (2nd globally)	• Coal and petroleum coke accounts for approximately 85% of India's cement-sector final energy demand[62] • Emission intensity of 0.63 t CO_2/t cement[63]	• Included in the Carbon Credit Trading Scheme (CCTS) emission-intensity target with legally binding GHG targets • National Institution for Transforming India developed a roadmap for cement sector decarbonisation	**Key players**: Global Cement & Concrete Association (GCCA) India - comprised of cement manufacturing representing over 60% of production capacity[64] **Key measures:** • **Electrification:** Ultratech piloting advanced technologies to electrify kiln heat and elimination of CO_2 from calcination[65] • **Target setting:** Four of India's largest producers (UltraTech, Dalmia, Shree, Ambuja) have adopted Science Based Targets in line with the Paris Agreement[66]
Indonesia	65 (8th globally)	• Coal dominates energy mix with a smaller share of electricity, renewable, and diesel[67] • Emission intensity of 0.63-t CO_2/t cement [68]	• NDC target for cement's clinker ratio. • Reduce the clinker ratio from 81 percent to 65 percent by 2030 by promoting alternative raw materials[69] • Ministry of Industry has adopted a five-pillar decarbonisation strategy for the cement industry.	**Key players:** Semen Indonesia (SIG); Indocement; Conch Cement Indonesia; Cemindo Gemilang **Key measures:** • ***Thermal substitution*:** SIG reached 9.77% in 2025, with a 2030 target of 20%

Country	2024 Share of global Production Volume *million tonnes* (ranking)[57]	Profile	National Policies/ Targets	Corporate Action
Brazil	68 (7th globally)	• Coal and Petroleum coke account for more than half of sector energy consumption; Remaining from alternative fuels including waste and biomass[70] • Emission intensity of 0.58-ton CO_2/t cement[71]	• Cement Technology Roadmap by National Union of Cement Industry (SNIC) commits the industry to cutting carbon intensity by 33 percent by 2050 • National Industrial Decarbonisation Strategy (ENDI) explicitly lists cement among the "traditional sectors" the strategy covers. The sector is also part of 'Brazil's National Mitigation Strategy' • Legal framework for low-carbon H2 production encourages application in sectors including cement	**Key players:** Votorantim Cimentos; InterCement; CSN Cimentos **Key Measures:** • ***Co-processing***: InterCement reports a national-average biomass share of thermal energy at 27 percent[72]; Votorantim Cimentos achieved 32 percent in Brazil in 2024 with a 53 percent target for 2030[73] • ***Clinker substitution***: Votorantim cut its clinker factor to 72.5% (2024)[74] and is targeting 32% of final[75] product made of alternative raw materials by 2030
Russia	65 (9th globally)	• Emission intensity exceeding 0.60t CO_2 /t cement[76]	• GHG intensity indicators embedded in the Best Available Techniques (BAT) system for clinker and cement[77] • Federal Law 296-FZ makes GHG reporting mandatory for large emitters[78]	**Key Players:** Siberian Cement Holding Company; CEMROS; Novoroscement **Key measures:** • Clinker substitution and alternative fuels activities remain limited

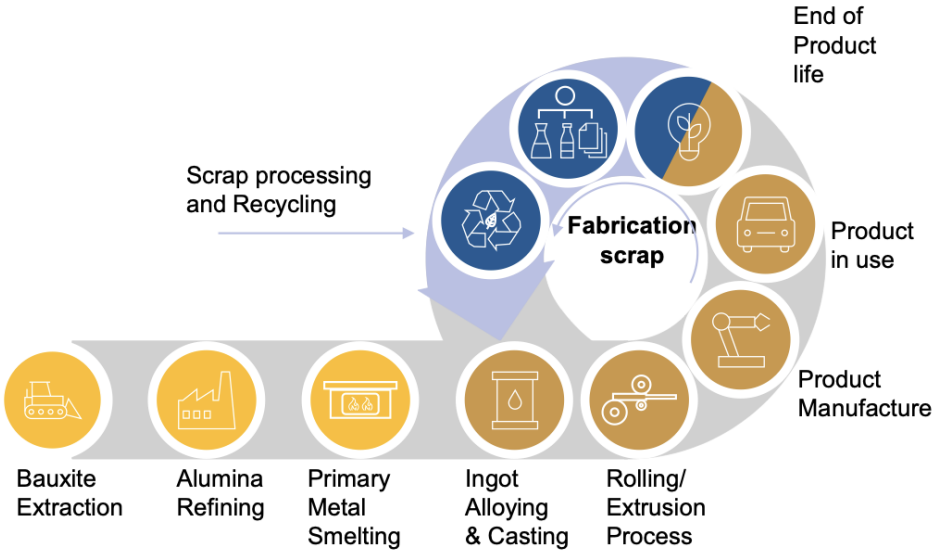
Source: Authors' own, using sources as cited.

2.3 Aluminium

2.3.1 Why is the Aluminium sector difficult to decarbonise?

Aluminium does not occur in its metallic form and is produced through a multi-step industrial value, through two production processes. The primary aluminium production process involves metals extracted from raw materials, while the secondary aluminium production relies on pre- and post-consumer scrap recycling.

Figure 3: Lifecycle of Aluminium



Source: Niti Aayog[79]

In the primary aluminium production method, aluminium oxide is extracted from bauxite ores and then purified into alumna (white powder form) which is then converted to aluminium by electrolysis, usually using carbon-intensive fossil fuel-powered electricity. The metal after alloying and casting, is rolled or extruded to produce various semi-finished and finished products. Following the end of their useful life, these are returned to the production cycle via scrap sorting, processing, and recycling. The recycling stage gives rise to the secondary aluminium production, one of the important avenues for circularity and emission reduction. Recycling of aluminium scrap is intrinsically much more sustainable compared to primary production, using 95 percent less energy than the production of primary aluminium.[80] The emission intensity of aluminium production also depends vastly on the type of feedstock used and the source of energy powering the process.

Table 4: Primary and Secondary Aluminium Production Divided Into Five Categories, Each Representing a Different Profile of Emissions

Primary (Grey): Conventional primary aluminium with the highest emissions, reliant on fossil fuels and less efficient technologies.
Primary (Low CO_2): Primary aluminium with reduced emissions achieved by using cleaner sources and improving energy efficiency in the production process but higher emissions than ultra-low.
Primary (Ultra-low CO_2): Primary aluminium produced with emissions <2 tCO_2/tAl achieved through advanced technologies and RE integration.
Secondary (Grey): Aluminium originating from pre-consumer scrap may have higher emissions attributed to the energy-intensive nature of recycling processes and the quality of scrap used.
Secondary (Green): This route utilises aluminium from post-consumer scrap and green energy sources.

Source: Niti Aayog[81]

The lion's share, almost 70 percent of global aluminium production, still comes from the grey primary route and relies heavily on fossil fuel combustion and emission-intensive processes. The rest consists of secondary aluminium , both green and grey, depending on availability of scrap supply and energy mix during recycling.[82]

The total global aluminium supply is projected to rise from 95 MT in 2022 to 136 MT by 2040. The share of high-emission primary grey aluminium will decline from around 71 percent in 2020 to just about 27 percent in 2040, with producers turning to greener alternatives. Not only will the volume rise; the composition of supplies will also undergo significant changes. Currently, China dominates aluminium production by miles accounting for 68 percent of global primary aluminium, followed by India and Russia which each contribute around 6 percent.[83]

Process Related: Chemical processes involved in converting bauxite into alumina and then alumina into primary aluminium is significantly carbon-intensive. During alumina refining, emissions are primarily associated with the heat required for calcination, while during aluminium smelting, emissions arise from the oxidation of carbon anodes used in the electrolysis process. Smelting can also generate perfluorocarbons (PFCs), highly potent greenhouse gases, during so-called *anode effects*. There is some potential to reduce process-related emissions through improved process efficiency, cleaner calcination technologies, changes in anode technology.

Energy Related: Energy-related emissions are the dominant source of emissions in the primary aluminium production method given smelting requires very large quantities of electricity.

Electricity holds around 76 percent of the identified abatement potential, making the decarbonisation of electricity central to the sector's transition.[84] This makes the shift towards renewable electricity through solar and wind generation, including potentially dedicated or on-site generation one of the most important pathways for reducing emissions. Other measures include biomass co-firing in captive power plants as an interim option, low-carbon firm power and where applicable, carbon capture applied to power generation. Recycling provides an additional route to reduce energy requirements as secondary aluminium avoids much of the energy-intensive primary production process.

The primary challenges in decarbonising the aluminium sector are:

1. Carbon-Intensive Electricity and Process Heat

Primary aluminium production is highly electricity-intensive, both at the alumna refining stage which requires significant process heat as well as in the smelting process which generate PFCs due to the use of carbon anodes. Alternatives such as inert anodes, alternative calcination processes, and cleaner anode-baking systems are available but not yet commercially scalable. Clean electrification, hydrogen, biomass and other lower-carbon fuels can support low-carbon energy requirements._

2. Weak Recycling and Scrap-Management Systems

Scrap availability is a challenge in secondary aluminium production. Post-consumer scrap is often collected through informal channels, resulting in inconsistent supply, weak sorting and poor traceability. Limited digitisation and automation particularly among small-scale producers constrains processing and quality control.

3. Infrastructure and Policy Gaps

Policies pertaining to low-carbon aluminium production and recycling remain uneven, fragmented and unclear which fails to provide a strong policy signaling disincentivising producers from pursuing low-carbon aluminium production pathways. Stronger policy coordination, quality standards and market mechanisms are therefore needed to formalise recycling, mobilise investment, and develop secondary- aluminium markets.

2.3.2 Aluminium Decarbonisation Pathways in Major BRICS+ Producing Economies

Table 5: Overview of Top BRICS+ Aluminium Producers

Country	2024 Share of Global Primary Aluminium Production Volume million tonnes (ranking)[85]	Profile	National Policies/Targets	Corporate Action
China	43 (1st globally)	• Dominated by coal-powered smelting followed by hydropower and solar, wind[86] • Emission intensity of 14.8 tCO_2e/t Al[87]	• Action Plan for Energy Conservation and Carbon Reduction in the Electrolytic Aluminium Industry (2024) • Energy Conservation and Carbon Reduction Action Plan 2024–2025 (non-ferrous metals): • Aluminium included under the national ETS • Metallurgy sector targeted in the implementation Plan for Accelerating Clean and Low-Carbon Hydrogen Application in the Industrial Sector • 14th Five-Year Plan for the Circular Economy set a target of more than 15 Mt of recycled aluminium use by 2027	**Key players:** Chinalco; China Hongqiao; Shandong Xinfa; East Hope; Huomei; Henan Mingtai Aluminium **Key measures:** • ***Renewable energy*** - Hongqiao relocating smelting capacity to hydropower-rich region[88] • ***Recycling***: Henan Mingtai Aluminium largest recycled aluminium producer leading closed-loop aluminium manufacturing[89]
India	4.2 (2nd globally)	• Coal-powered smelting dominates [90] • Primary aluminium emissions intensity at 20- 21 tCO_2e/t Al[91]	• Included in the Carbon Credit Trading Scheme (CCTS) emission-intensity target (scope 1) with legally binding GHG targets • Renewable Consumption Obligation framework includes aluminium sector	**Key measures:** Hindalco; Vedanta; Bharat Aluminium Co. Ltd.(BALCO); National Aluminium Co. Ltd. (NALCO) **Key players:** • ***Renewable energy*:** Hindalco worlds-first round-the-clock renewable PPAs for smelting[92]; Target for 2.5 GW of RoundThe-Clock (RE-RTC) renewable energy capacity by 2030, supported by power purchase agreements and renewable project[93] • ***Fuel switching***: Vedanta biomass co-firing; Diesel generators replaced with solar power[94]

Country	2024 Share of Global Primary Aluminium Production Volume million tonnes (ranking)[85]	Profile	National Policies/Targets	Corporate Action
Russia	3.8 (3rd globally)	• 98% based on renewable energy supplied by hydro power plants in Siberia[95]	• State Low-Carbon Development Strategy lists aluminium as a key sector for energy/resource efficiency improvement and conversion to the inert anode technology	**Key players**: RUSAL **Key measures:** • ***Inert Anode Technology*:** RUSAL confirmed the production of Grade A7 aluminium needed to transition the inert anode technology from pilot to full-scale deployment[96] • CCUS**:** In 2025, Rusal registered Russia's first CCUS project in the national carbon unit registry[97]
UAE	2.7 (5th globally)	• Dominated by natural gas-combined cycle captive plants; solar and nuclear also used via the national grid[98] • Emission intensity of 10.4 tCO_2e/t Al[99]	• Industrial Decarbonization Roadmap explicitly targets among the hard-to-abate sectors targeting emission reduction • Aluminium sector among the targeted industries in the national-hydrogen-strategy • EGA part of the Hydrogen Leadership Initiative, the Abu Dhabi Hydrogen Alliance and the National Hydrogen Technical Committee	**Key players**: Emirates Global Aluminium (EGA) **Key measures:** ***Renewable energy*:** Grid integration replacing captive gas generation via EGA-TAQA-DubalHolding-EWECinitiative[100] • ***Generation efficiency*:** commissioning high efficiency turbines reducing plant power and smelting emissions by about 10 percent[101] • ***Recycling***: EGA aggressive recycling expansion between 2024 and 2026 acquiring the collection, sorting, and processing infrastructure[102]

Country	2024 Share of Global Primary Aluminium Production Volume million tonnes (ranking)[85]	Profile	National Policies/Targets	Corporate Action
Brazil	1.1 (9th globally)	• Dominated by hydropower smelting[103] • Brazilian primary aluminium at an average 4.5 to 6.5 tCO_2e/t Al[104]	• Legal framework for Low-Carbon Hydrogen production encourages application in sectors including aluminium	**Key players**: Albras (Alumínio Brasileiro S.A.); CBA Companhia Brasileira DE Alumínio; Latasa **Key measures:** • ***Refinery fuel switching*** - converting Alunorte, the largest alumina refinery outside China, from heavy fuel oil to natural gas • ***Recycling***: Recycled aluminum in Brazil accounts for 59% of domestic aluminium consumption, compared to a global average of 29%[105]

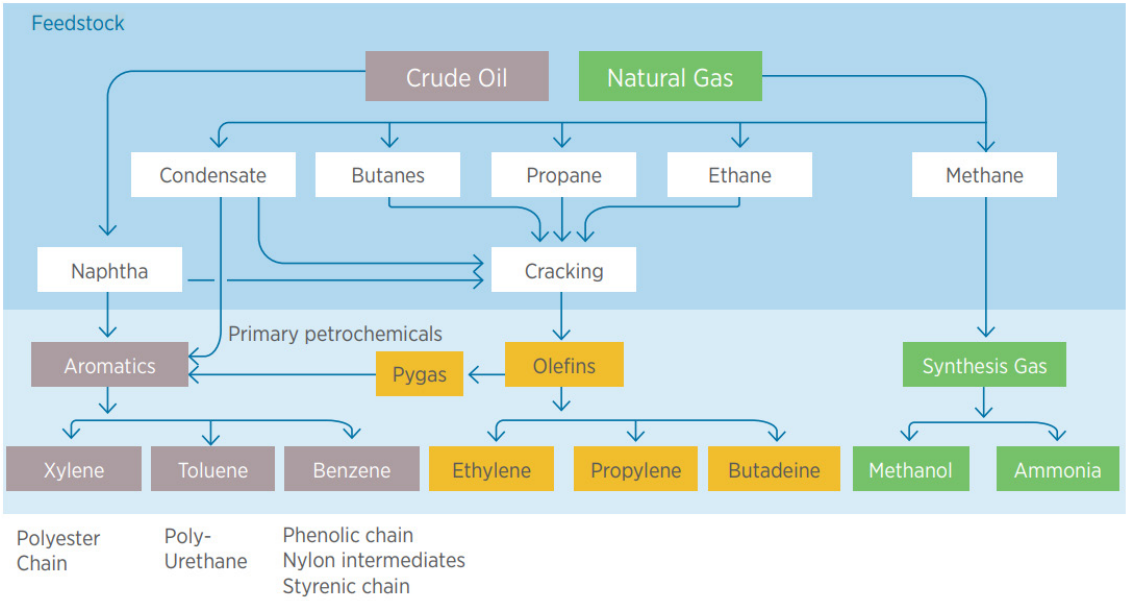
Source: Authors' own, using sources as cited.

2.4 Chemicals, Ammonia and Petrochemicals

2.4.1 Why is the Chemicals, Ammonia and Petrochemicals sector difficult to decarbonise?

The processing of crude oil and natural gas produces chemicals and petrochemicals which are crucial to people's daily lives given its pervasive use across industries, households, and technologies. Given that crude oil and natural gas are the feedstock in chemicals and petrochemicals production, these are emissions-intensive. Majority of the emissions, however, stem from a small number of chemicals, particularly ammonia, methanol and steam cracking products which include ethylene, propylene, butadiene and aromatics.[106]

Figure 4: Overview of Feedstocks of Petrochemical Products



Source: IRENA[107]

In 2023, the production of these primary chemicals—ammonia, methanol and High Value Chemicals (HVCs)—were responsible for approximately 1,343 Mt of direct CO_2 emissions, or about three-fourths of the total chemical and petrochemical sector's CO_2 emissions. The lion's share of the total direct CO_2 emissions from primary chemicals stem from ammonia production at 45 percent, followed by methanol production at 28 percent, while the rest comes from the production of HVCs. Emissions from Primary chemical production emerge in equal measure from energy used in production processes and from feedstock use, and therefore both have to mitigated in tandem in order to reduce emission intensity from this sector.[108]

Ammonia is a crucial commodity, given almost 85 percent of it is dedicated to the production of synthetic nitrogen fertilisers, making it critical to global food security. In 2022, 187 Mt of ammonia was produced globally, primarily sourced from natural gas (72 percent) and coal (26 percent). Ammonia production is increasing at an average annual growth rate of 1 percent. Replacing conventional ammonia with renewable ammonia can significantly reduce emissions in the sector. Most of the ammonia production relies on the Haber-Bosch process where natural gas acts as both the feedstock and energy source[109].

In contrast, renewable ammonia can be produced from green hydrogen, generated through renewable powered electrolysis, which is combined with nitrogen separated from air through an ammonia synthesis process. While this technology is commercially available, the cost differential between the two production process remains a barrier to adoption. The production cost of natural gas and coal-based ammonia production ranges between US$110 per tonne and US$340 per tonne, compared with an estimated US$720–1,400 per tonne for renewable

ammonia produced at new facilities. However, these costs are expected to decline improving its potential cost-competitiveness.[110]

Methanol is an important feedstock used to manufacture products including solvents, resins and pharmaceuticals. In 2022, around 106 Mt of methanol was produced globally, primarily sourced from natural gas (65 percent) and coal (35 percent) and much less from renewable sources (0.2 percent). Methanol production grew at an average annual growth rate of 6.5 percent. Renewable methanol presents two possible pathways: biomethanol and e-methanol. Biomethanol is derived from biogenic feedstocks through processes such as gasification or anaerobic digestion processes. Potential biomass feedstocks include agricultural and forestry waste, landfill biogas, sewage, municipal solid waste, and black liquor from the pulp and paper industry. The production cost of natural gas-based and coal-based methanol ranges between US$100-200 per tonne and US$150-250 per tonne, respectively, while production costs of biomethanol are significantly higher, depending on the feedstock, with an estimated range between US$327 per tonne and US$1,013 per tonne. On the other hand, e-methanol is derived from green hydrogen and a sustainable source of carbon, potentially CO_2 from bioenergy with carbon capture and storage (BECCS) or direct air capture (DAC). However, e-methanol faces an even greater cost disadvantage, with estimated production costs ranging from US$800 to US$2,400 per tonne.[111]

High-value chemicals (HVCs), including olefins (primarily ethylene, propylene, and butadiene) and aromatics (including benzene, toluene, and xylenes), serve as fundamental feedstocks across industries, including plastics, synthetic organic fibres like nylon, and other polymers. Global demand for HVCs has expanded at an average annual rate of approximately 3 percent. In particular, 90 percent of plastic production today, which has doubled between 2000-2023 reaching 414 Mt, continues to come from fossil feedstocks while the bio-based plastics constituted a mere 0.7 percent in 2023. Globally, only around 9 percent of global plastics production comes from the recycling of plastic waste.[112]

Conventional petrochemical feedstocks can be replaced with bio-based alternatives including bioethanol, bio-ethylene and bio-aromatics; however, high production costs and limited technological maturity have constrained wider adoption. For instance, bio-ethylene can be produced from bioethanol, although it currently accounts for less than 1 percent of global ethylene production. Bio-based feedstocks can also be produced by synthesising hydrocarbon which involves combining green hydrogen with sustainable sources of carbon. Reuse and recycling of petrochemical products offers further potential to mitigate emissions but its wider adoption is constrained by costly sorting, processing and treatment processes. In plastics recycling, mechanical recycling continues to dominate, while chemical recycling accounts for less than 0.1 percent of total plastics recycling.[113]

The need is for a combination of both demand-side and supply-side measures. Some technological pathways are already commercially available and can be scaled up in the coming decades. These include energy efficiency improvements, substitution of fossil fuels with bio-based feedstocks for some chemicals, electrification of multiple heating processes, and renewable hydrogen. Applying the principles of the circular economy in the sector would have economic, social and environmental benefits. Circular economy measures generally include increased reuse, mechanical and chemical recycling, material substitution and the use of sustainable feedstocks to reduce demand.

2.4.2 Petrochemicals and Ammonia Decarbonisation Pathways in Major BRICS+ Producing Economies

Table 6: Overview of Top BRICS Petrochemicals and Ammonia Producers

Country	Ammonia Production (*mt*)[114] (2024)/ Petrochemical Exports (%)[115] (2025) (Global Ranking)	Profile	National Policies/ Targets	Corporate Action
China	Ammonia – 49 (1st globally) Petrochemicals – 15.4% of global exports (1st globally)	• 85 percent of ammonia production runs on coal gasification [116] • Naphtha accounts for more than 70% of China's olefins feedstock[117]	• Action Plan for Energy Saving and Carbon Reduction in the Synthetic Ammonia Industry • Ammonia sector targeted in the implementation Plan for Accelerating Clean and Low-Carbon Hydrogen Application in the Industrial Sector	**Key players**: ***Fertilisers***: Sinofert/Sinochem; Yuntianhua; Envision Energy ***Petrochemicals***: Sinopec; PetroChina; Wanhua Chemical; Rongsheng **Key measures:** • ***Green ammonia***: Envision energy runs a commercial-scale, certified, off-taken green ammonia facility[118] • ***Sinochem***: Utilising CO_2 liquification facilities for enhanced oil recovery[119] • ***Sinopec:*** Renewable electricity, alternative biomass fuel combustion, and energy efficiency improvements[120]

Country	Ammonia Production (*mt*)[114] (2024)/ Petrochemical Exports (%)[115] (2025) (Global Ranking)	Profile	National Policies/ Targets	Corporate Action
India	Ammonia – 15 (2nd globally) Petrochemicals – 4.7% of global exports (7th globally)	• Ammonia/ Fertiliser fleets dominated by natural gas Steam Methane Reforming (SMR) • Ethylene production dominated by ethane and naphtha fed crackers[121]	• Among the focuses of the National Green Hydrogen Mission is demand aggregation for green ammonia • The Perform, Achieve and Trade (PAT) scheme includes petrochemical crackers and several chemical subsectors • Renewable Consumption Obligation framework includes fertiliser, petroleum-refinery, and petrochemical	Key players: Reliance (petrochemicals) PCBL (petrochemicals) IFFCO (Fertilisers) Coromandel International Limited (CIL) (Fertilisers) National Fertilizers Ltd (NFL) Key measures: • ***Renewable energy:*** Reliance is building an integrated solar, storage, electrolyser and green-hydrogen complex[122] • ***Fossil fuel substitution***: PCBL replacing conventional fossil-based raw materials with oil and recovered carbon black from recycled tyres[123] • ***Green ammonia***: IFFCO and CIL exchanged 10-year Green Ammonia Purchase and Supply Agreements under India's SIGHT[124]
Saudi Arabia	Ammonia – 5.2 (6th globally) Petrochemicals – 3.0% of global exports (9th globally)	• Petrochemical Feedstock is primarily ethane followed by propane and LPG derivatives and naphtha[125]	• Saudi Energy Efficiency Program • CCU in petrochemicals (CO2-to-methanol and urea recycling) is positioned as both a decarbonisation tool and an industrial strategy under Vision 2030	**Key players**: Saudi Basic Industries Corporation (SABIC); Ma'aden **Key measures:** • ***CCUS and ultra-low-carbon ammonia****:* Ma'aden captures CO_2 generated by ammonia production for industrial use, alongside waste heat recovery to generate clean energy[126] • ***Electrification and CCU***: SABIC piloting an electrically heated steam cracker and operates a 500 ktCO_2/year carbon-capture unit[127]
Russia	Ammonia- 15 (3rd globally) Petrochemicals - 0.9% of global exports (20th globally)	• Ammonia production based on low-cost domestic natural gas[128]	-	**Key players (Fertilisers):** Acron; Togliattiazot; EuroChem **Key measures:** • ***By-product reuse:*** use ammonia-process CO_2 as feedstock in downstream nitrogen products

Country	Ammonia Production (*mt*)[114] (2024)/ Petrochemical Exports (%)[115] (2025) (Global Ranking)	Profile	National Policies/ Targets	Corporate Action
Indonesia	Ammonia - 5.7 (5th globally) Petrochemicals – 3.0% of global exports (10th globally)	• Majority of ammonia production is fossil fuel derived[129]	• Revised NDC explicitly mentions mitigation action for the ammonia production sector • Green Industry Standard applied to fertiliser plants • National Hydrogen and Ammonia Roadmap • State-owned PT Pupuk Indonesia decarbonisation roadmap targeting 96 percent GHG reduction by 2050 across fertiliser and petrochemical complexes	**Key players:** Pupuk Kaltim; Pupuk Sriwidjaja **Key measures:** • ***Blue ammonia with CCS*** : seven projects converting largest grey ammonia fleet in Asia to blue[130] • ***Hybrid green ammonia***: in parallel to natural gas ammonia production the plant integrates water electrolysis and renewable energy to produce green ammonia from renewable hydrogen[131]

Source: Authors' own, using sources as cited.

Chapter 3

Policy Recommendations

THE RECOMMENDATIONS OUTLINED in this section include both sector-specific and cross-sectoral. The applicability and intensity of the proposals will vary, accounting for the differences in industrial maturity and development across the BRICS+ countries and reflecting their distinct emissions profiles, technological requirements, and national industrial decarbonisation targets. At the same time, these differences offer tremendous potential to collaborate and cooperate to build a robust, adaptable, and sustainable industrial ecosystem, well-poised for a net-zero future.

To facilitate this cooperation, this report proposes establishing a working group to assess the feasibility and urgency of these recommendations across a timeline, track and monitor implementation progress, and promote knowledge sharing and dissemination of best practices among the BRICS+ countries.

3.1 Sector-Specific Policy Recommendations

Table 7: Policy Recommendations for BRICS+ Industrial Decarbonisation, by Sector

Industry	Key Decarbonisation Priorities	Recommended Policy Interventions	Opportunities for BRICS+ Cooperation
Iron and steel	Decarbonising primary steel production	• Develop phased transition pathways from BF BOF towards lower-emission DRI-EAF production. • Support hydrogen-based DRI through production incentives, green hydrogen procurement and industrial demonstration projects • Promote natural gas-based DRI as a potential transitional pathway, subject to lifecycle emissions safeguards and compatibility with longer-term decarbonisation. • Explore CCUS for existing integrated steel facilities where alternative production routes are not yet commercially viable	• Joint investment in hydrogen-based steelmaking and DRI technologies. • Develop regional HBI production and trade partnerships, linking resource rich economies with steel-making centres • Facilitate technology transfer and joint demonstrations involving steel producers and technology providers.
	Expanding secondary steel production	• Strengthen scrap collection, segregation, processing and traceability systems. • Introduce incentives for scrap-based EAF production and improve access to high-quality scrap. • Establish scrap quality and grading standards to facilitate domestic and cross-border trade. • Improve end-of-life product recovery, particularly from construction, automotive and manufacturing sectors.	• Develop common scrap classification and quality standards. • Facilitate responsible cross-border scrap trade and recycling partnerships. • Exchange best practices in scrap processing, sorting and digital material tracking.
	Improving energy efficiency and industrial performance	• Introduce mandatory energy audits and sector specific efficiency benchmarks. • Promote waste gas recovery, waste-heat utilisation, process optimisation and electrification. • Link industrial incentives and financing to measurable emissions intensity improvements	• Share best available technologies and industrial efficiency benchmarks. • Develop joint demonstration projects for waste heat recovery and industrial electrification.

Industry	Key Decarbonisation Priorities	Recommended Policy Interventions	Opportunities for BRICS+ Cooperation
Cement	Reducing process emissions through clinker substitution	• Establish declining clinker-to-cement ratio targets, supported by performance and quality standards. • Accelerate the deployment of calcined clay, limestone calcined clay cement(LC3), fly ash and other suitable supplementary cementitious materials. • Support research into locally available alternative binders and cement formulations. • Introduce green public procurement requirements for low-carbon cement and concrete.	• Joint R&D on LC3 and alternative cementitious materials. • Exchange technical expertise on material performance, • durability and standardisation. • Facilitate research partnerships to identify locally available clinker substitutes.
	Decarbonising kiln heat and fuel consumption	• Expand the use of sustainable biomass and waste- derived fuels through co- processing. • Introduce energy-efficiency standards for kilns and promote waste-heat recovery. • Support electrification of suitable thermal processes and development of alternative high- temperature heating technologies • Strengthen sustainable biomass and waste collection infrastructure.	• Technology exchange on alternative fuels, kiln efficiency and electrification. • Joint demonstration projects for advanced industrial heating technologies. • Exchange best practices in municipal and industrial waste utilisation.
	Managing residual process emissions	• Develop CCUS demonstration projects for cement facilities, part icularly in industrial clusters with suitable geological storage. • Establish enabling regulations for CO_2 capture, transport, utilisa tion and permanent storage. • Ensure CCUS complements rather than delays clinker substit ution and energy efficiency improvements.	• Joint research on carbon capture technologies and geologi cal storage potential. • Explore shared CO_2 transport and storage infrastructure where commercially and geogra phically feasible.

Industry	Key Decarbonisation Priorities	Recommended Policy Interventions	Opportunities for BRICS+ Cooperation
Aluminium	Decarbonising electricity and primary production	• Expand access to reliable, round-the clock renewable and other low-carbon electricity through dedicated generation, PPAs and grid integration. • Improve energy efficiency in smelting and alumina refining. • Promote lower carbon process heat, including electrification and sustainable fuel alternatives. • Support commercialisation of inert anodes and other technologies that reduce process emissions and perfluorocarbon formation.	• Develop renewable electricity partnerships for energy-intensive aluminium production • Facilitate technology transfer and joint R&D on inert anodes, efficient smelting and alumina refining. • Explore cross-border clean electricity trade where feasible
	Scaling secondary aluminium production	• Formalise scrap collection and recycling systems, including integration of informal waste-recovery channels. • Invest in automated sorting, scrap processing and quality-control infrastructure. • Introduce recycled-content requirements and incentives for secondary aluminium use. • Strengthen product traceability and extended producer responsibility mechanisms.	• Develop common scrap-quality and recycled-content standards. • Facilitate partnerships in recycling technology, collection systems and secondary aluminium production. • Encourage closed-loop recycling arrangements between manufacturers and downstream industries.
	Strengthening low-carbon aluminium markets	• Introduce product-level emissions benchmarks and credible certification for low- carbon aluminium. • Encourage green procurement in construction, automotive and renewable energy manufacturing. • Improve emissions monitoring across alumina refining, smelting and casting.	• Improve interoperability of product carbon footprint methodologies • Facilitate trade and investment in low-carbon aluminium value chains.

Industry	Key Decarbonisation Priorities	Recommended Policy Interventions	Opportunities for BRICS+ Cooperation
Chemicals, Ammonia and Petrochemicals	Decarbonising ammonia and methanol production	• Accelerate the deployment of renewable hydrogen for green ammonia and methanol production. • Support industrial demand aggregation, long- term offtake agreements and production incentives to reduce the green premium. • Improve energy efficiency in conventional ammonia and methanol facilities during the transition. • Explore CCUS enabled production where appropriate, with robust lifecycle emissions accounting.	• Develop green hydrogen, ammonia and methanol trade partnerships. • Facilitate long-term offtake agreements between producers and fertiliser, shipping and industrial consumers. • Share expertise in electrolysers, hydrogen storage and industrial integration.
	Transitioning Petrochemical feedstocks	• Promote sustainable bio- based alternatives, including bioethanol, bio-ethylene and bio aromatics. • Support research and commercialisation of synthetic hydrocarbons produced using green hydrogen and sustainable carbon sources. • Improve energy efficiency and electrify suitable processes, including steam cracking. • Assess feedstock sustainability and lifecycle emissions to avoid unintended environmental impacts.	• Joint R&D on bio-based feedstocks and e-chemicals • Facilitate technology partnerships in electrified steam cracking and alternative chemical production routes. • Develop sustainable feedstock certification and traceability mechanisms.
	Advancing circularity in petrochemicals and plastics	• Expand mechanical recycling through better collection, sorting and processing infrastructure. • Support chemical recycling demonstration projects where lifecycle emissions and economics justify deployment. • Introduce recycled-content requirements, reuse targets and extended producer responsibility mechanisms. • Promote industrial symbiosis and reuse of chemical by- products.	• Share recycling technologies and best practices in waste management. • Develop common standards for recycled feedstocks and plastics traceability. • Facilitate investment in regional recycling and processing infrastructure.

Source: Authors' own, using IEA,[132,133] JRC,[134] and IRENA.[135]

3.2 Cross-Sector Policy Recommendations

1. Establishing Sectoral Decarbonisation Targets, Regulatory Policies, and Standards

While most BRICS+ countries have an economy-wide net-zero target, few have established specific sectoral decarbonisation targets for the energy-intensive industries. Introducing interim sector-specific emission reduction targets for iron and steel, cement, aluminium, and petrochemicals, tailored to national industrial structures and capabilities, would provide a clear policy signal to businesses, investors and technology innovators. Such targets should be supported by phased regulatory frameworks, sector-specific standards and targeted incentives without imposing a disproportionate compliance cost on small and medium-sized enterprises (SMEs).

Sectoral policies should also prioritise energy efficiency, waste-heat recovery, fuel switching, renewable electricity integration, electrification, and improved material efficiency and scrap recycling. Furthermore, providing dedicated government financing through direct grants and tax incentives, and introducing carbon limits or taxes can provide capital incentives. Together, these measures can accelerate technology adoption, strengthen industrial competitiveness, and improve access to international markets. For instance, India has allocated approximately US$2.06 billion through FY 2029-30 for its hydrogen strategy.[136] Indonesia has introduced a regulatory framework for carbon capture and storage (CCS), providing greater clarity and governance for the deployment of this technology—although gaps remain as current regulatory treatment of CCS and CCUS focus on oil and gas industries.

2. Transition Finance and Carbon Market

Transition finance is crucial for supporting investments in industrial decarbonisation. The BRICS+ working group should focus on establishing an interoperable sustainable finance taxonomy which can be instrumental in mobilising cross-border investment and direct financial resources towards industrial decarbonisation activities. Several BRICS+ members have already gained experience in this area, including Brazil through its Sustainable Taxonomy and Indonesia's Taxonomy for Sustainable Finance (TKBI).[137] Clear and consistent regulatory frameworks and sector-specific taxonomies across BRICS+ countries are needed to increase demand for low-carbon products, attract investments, and provide clear guidance on low-carbon transitions. The working group should leverage platforms such as the New Development Bank, World Bank Group, and International Finance Corporation to explore diversified infrastructure financing models and expand the scale of funding for infrastructure projects. Focus should also be on improving lending terms, and reduce financing costs, utilising financing models, such as green bonds and infrastructure funds.

Carbon markets offer a complementary instrument to incentivise industrial emission reductions. By incorporating the cost of carbon emissions in economic decision-making, they can create incentives for industries to adopt lower-emissions technologies. However, their effectiveness is contingent on robust monitoring, reporting, and verification (MRV) systems and carbon accounting, as well as transparent price discovery. The 2026 New Delhi Declaration reaffirmed support for cooperation on carbon markets, particularly through capacity building and knowledge exchange, while also endorsing the implementation of the Memorandum of Understanding on the BRICS Carbon Markets Partnership.[138] BRICS+ members such as China, which operates the world's largest emissions trading system, and India, which has established a national carbon credit mechanism, offer experience in developing carbon market regulations and MRV systems. Drawing on these experiences, cooperation should focus on improving the consistency, transparency, and credibility of industrial emissions data, establishing credible product-level carbon accounting and certification mechanisms while laying the groundwork for establishing national carbon market mechanisms among the BRICS countries.

3. Developing Low-Carbon Industrial Clusters and Shared Infrastructure

The expansion of BRICS has strengthened its position as a hub for regional connectivity, with new members providing strategic links across major trade and logistics networks.[139] Building on these geographical advantages, India's 2026 BRICS chairmanship has supported the development of the Global Value Chains Action Plan 2026–2030, aimed at strengthening supply-chain resilience, efficiency, diversification, and connectivity.[140] Such cooperation could facilitate the development of integrated value chains supporting the production, distribution, and consumption of low-carbon industrial products across BRICS+ economies.

Decarbonising the industrial sector will require both modernisation of existing industrial assets and the development of integrated low-carbon industrial clusters. This includes prioritising retrofitting existing facilities, improving energy efficiency, electrifying industrial processes, deploying low-carbon hydrogen and advancing CCUS and other emerging technologies. Shared infrastructure for clean electricity, hydrogen production and distribution, carbon transport and storage, and industrial logistics will be critical to scaling these technologies and reducing deployment costs, by leveraging strengths in raw materials, renewable energy resources, and technological expertise to develop lower-carbon industrial value chains and hubs.

4. Advancing Circularity and Resource Efficiency

Expanding Circularity and Resource Efficiency are important levers to reduce dependence on carbon-intensive primary production methods through recycling, material recovery, industrial waste reuse, secondary production and utilising sustainable feedstock alternatives. These offer opportunities for cooperation among the BRICS+ countries, particularly through the recovery, processing, and reuse of industrial materials. A BRICS+ circularity platform could

facilitate technology transfer in scrap sorting and preprocessing, promote common quality standards for secondary materials, and support digital material-tracking systems to improve transparency and resource recovery. Such collaboration could strengthen secondary-material supply chains and improve the efficiency of industrial resource use across member economies.

Beyond material circularity, CCUS presents opportunities for shared infrastructure and carbon capture technology development. As of 2023, around 80 percent of active carbon capture initiatives globally focus on enhanced oil recovery;[141] thus there remains significant potential to expand carbon capture and permanent geological storage for emissions-intensive industries. A BRICS+ working group could support cooperation in geological storage-resource mapping, joint demonstration projects, and the development of shared CO_2 transport and storage infrastructure, including cross-border hubs where technically, economically, and legally feasible. Such initiatives could help support the gradual commercial deployment of CCUS technologies.

5. Research, Innovation, and a Skilling Ecosystem

Research and development (R&D), joint demonstration projects, and green skills development are essential and often the most underrated enabler in advancing industrial decarbonisation. Several of the decarbonisation technologies identified, including CCUS, renewable hydrogen, and energy storage, require continued research on technological innovation and cross-sectoral collaboration to progress from small-scale demonstration projects to commercial deployment across market types.

Alongside technological innovation, equally important is building workforce capabilities that can manage low-carbon industrial production systems. This will require targeted training and capacity-building programmes to strengthen technical and vocational expertise, for engineers, technicians, construction workers, industrial managers, and other professionals involved in the development, deployment, and operation of low-carbon technologies.

The working group can build on the BRICS Partnership on New Industrial Revolution (PartNIR), which promotes policy coordination, skills development, technological innovation, and industrial project cooperation. The proposed working group could leverage existing initiatives under PartNIR, including the BRICS Technology Transfer Center, BRICS-UNIDO Center for Industrial Competences Initiative, and BRICS PartNIR Innovation Center (BPIC).[142] Through these platforms, BRICS+ members can also focus on integrating advanced digital technologies, including artificial intelligence, automation, and data analytics, into industrial processes to improve energy efficiency, optimise resource use, and accelerate decarbonisation.

Chapter 4

Conclusion

WITH MAJOR PRODUCERS ACROSS the four hard-to-abate sectors covered in this report—Iron and Steel, Cement, Aluminium, and Chemicals, Ammonia and Petrochemicals—within the BRICS+, the group is well positioned to strengthen the Global South's role in shaping industrial decarbonisation pathways while maintaining industrial competitiveness in an evolving global landscape. Shared challenges, including economic constraints, access to reliable renewable energy, improving energy efficiency, and scrap feedstock availability, create multiple avenues and opportunities for knowledge sharing, co-development, and cooperation.

Advancing cooperation on industrial decarbonisation will require BRICS+ to build on existing regulatory and financial mechanisms, while mobilising greater private sector investment in low-carbon technologies, research and development, and industrial innovation. Institutions such as the New Development Bank can play an important role in transition financing and de-risking projects across the hard-to-abate sectors.

Ultimately, the effectiveness of the proposed sector-specific and cross-sectoral recommendations will be contingent on the grouping's ability to account for the evolving global trade dynamics, leverage domestic strengths, and accommodate differing development trajectories and national priorities. By identifying shared priorities and complementary strengths, BRICS+ can strengthen its collective industrial capabilities while accelerating low-carbon industrial transformation in a sustainable yet competitive industrial ecosystem.

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