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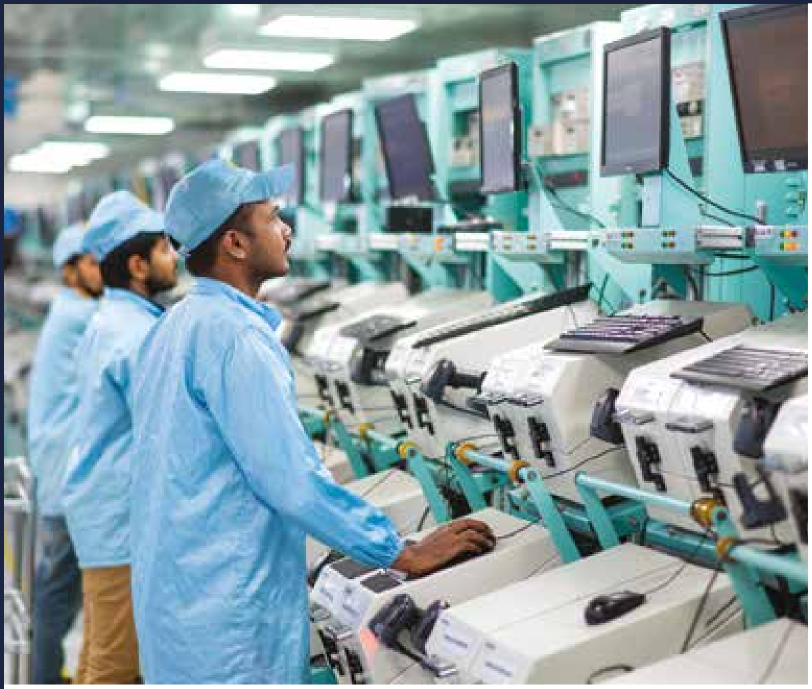
NITI Aayog

SCENARIOS TOWARDS VIKSIT BHARAT AND NET ZERO

SECTORAL INSIGHTS: INDUSTRY

(VOL. 4)



NITI Aayog
Government of India,
Sansad Marg, New Delhi–110001, India

Suggested Citation

NITI Aayog. (2026). Scenarios Towards Viksit Bharat and Net Zero - Sectoral Insights: Industry (Vol. 4)

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SCENARIOS TOWARDS VIKSIT BHARAT AND NET ZERO

SECTORAL INSIGHTS: INDUSTRY

(VOL. 4)

डॉ. वी.के. सारस्वत
Dr. V.K. Saraswat
सदस्य
Member
Tele : 23096566, 23096567
Fax : 23096603
E-mail : vk.saraswat@gov.in

सत्यमेव जयते

भारत सरकार
नीति आयोग, संसद मार्ग
नई दिल्ली - 110 001
Government of India
National Institution for Transforming India
NITI Aayog, Parliament Street,
New Delhi - 110 001

MESSAGE

India stands at a transformative moment in its development journey. As we pursue the twin national goals of becoming a developed, high-income economy by 2047 under *Viksit Bharat @2047* and achieving Net Zero emissions by 2070, our industrial sector will play a decisive role. Industry is both a driver of India's economic resurgence and a major contributor to national emissions and therefore lies at the heart of the challenge of balancing rapid growth with climate stewardship.

As our economy grows, India's demand for materials, energy, and infrastructure will rise sharply. This rise in production is not a choice but a necessity for lifting living standards for 1.4 billion Indians. Yet how we meet this demand will shape not only India's future, but also the global climate trajectory. Industry is already the largest end-use consumer of energy in India and a major contributor to emissions, heavily reliant on coal, oil, gas, and traditional biomass. But within this challenge lies a profound opportunity: to shift to clean power, to electrify processes, to adopt new fuels like green hydrogen, and to unlock efficiency gains in a relatively young industrial asset base.

Encouragingly, the contours of this "green industrial revolution" are already visible. The National Green Hydrogen Mission, our rapid expansion of renewables, the introduction of Limestone Calcined Clay Cement (LC3), the launch of industrial CCUS test beds, and plans for small modular reactors dedicated to industrial decarbonisation together signal a bold technological shift. India is not waiting on the sidelines; we are actively shaping the frontier – from clean fuels and electrification to circular economy practices and advanced materials.

The task before us now is to move from pilots and promise to scale and impact, supported by enabling policies, long-term finance, infrastructure for hydrogen and CO_2 transport, and modernised grids, alongside market-based mechanisms such as the Carbon Credit Trading Scheme (CCTS) to help accelerate cost-effective emission reduction across industry.

India has been an industrial and trading powerhouse before, from our famed textiles and “wootz” steel to our historic shipyards. In the 75 years since independence, we have again emerged as a leader in cement, steel, and a range of manufacturing sectors, often at best-in-class efficiency. We now have the chance to write the next chapter: to show that a populous, rapidly developing nation can grow, industrialise, and yet walk lightly on the planet.

This report on India’s industrial net-zero transition is both a roadmap and a call to action. It distils evidence, technology pathways, and policy options into a coherent vision of how our industries can become more productive, more competitive, and more sustainable.

I commend the authors and the many stakeholders who have contributed their expertise and experience to this work. I hope it will serve as a guiding document for policymakers, industrial leaders, financiers, and civil society as we collectively shape India’s industrial future.

In doing so, India will not only secure prosperity for its people but also offer the world a powerful example of “green growth” in practice. I am confident that with determination, innovation, and shared purpose, our industries will rise to this historic responsibility and help build a cleaner, more resilient, and more prosperous India for generations to come.

Saraswat

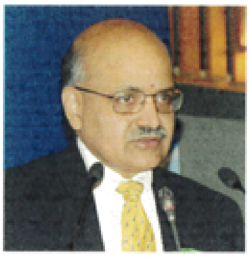
(Dr. V. K. Saraswat)

New Delhi
02.02.2026

बी. वी. आर. सुब्रह्मण्यम
B.V.R. Subrahmanyam
मुख्य कार्यकारी अधिकारी
Chief Executive Officer

सत्यमेव जयते

भारत सरकार
नीति आयोग, संसद मार्ग
नई दिल्ली - 110 001
Government of India
National Institution for Transforming India
NITI Aayog, Parliament Street,
New Delhi - 110 001
Tel. : 23096576, 23096574
E-mail : ceo-niti@gov.in



FOREWORD

Industry is integral to India's economic growth and the Hon'ble Prime Minister's vision of Viksit Bharat. The focus on infrastructure, urbanization, housing, and transport is expected to increase the demand for a range of industrial materials and commodities, such as cement, steel, aluminum, bricks, and petrochemicals.

The sector's energy needs are substantial, its processes complex, and many of its assets will operate for decades. Over the last 15 years, Indian industry has performed very well in improving the energy efficiency of manufacturing. In several sectors, Indian industry standards are comparable with the best in the world. Going forward, more needs to be done to align industries with the India's net zero pathway. New technologies and manufacturing processes will be required for further improvements in the energy efficiency of manufacturing.

Keeping in mind the complexities of this sector, NITI Aayog undertook a detailed assessment of the Industry sector as part of the study on developing India's pathways to Viksit Bharat and Net Zero. An inter-ministerial group was constituted to help develop a detailed roadmap for the industry sector. The working group examined all major industries segments, and assessed the relevance of new technologies, and alternate fuels.

The report identifies technology and policy options for industry to move on a path aligned with India's net zero goal. There is a major role for Circular Economy to reduce the demand for new materials and energy. The report also evaluates the role of emerging technologies such as green hydrogen, small and modular reactors and carbon capture, utilisation and storage. These technologies are still maturing in cost, scale, and commercial readiness.

I thank Dr. V. K. Saraswat, Member, NITI Aayog, for leading this working group. I also thank all the working group members for their keen involvement. I congratulate the NITI Aayog team led by Dr. Anshu Bharadwaj, Shri Rajnath Ram, Shri Venugopal Mothkoor, Dr. Anjali Jain and Shri Nitin Bajpai for their efforts on this report. This report will be essential in planning for India's industrial and sustainable future.

Dated: 4th February, 2026 **[B.V.R. Subrahmanyam]**

स्वच्छ भारत
एक कदम स्वच्छता की ओर

Authors and Acknowledgement

Chairperson

Dr. V. K. Saraswat
Member, NITI Aayog

Leadership

Sh. Suman Bery
Vice Chairman, NITI Aayog

Sh. B.V.R. Subrahmanyam
CEO, NITI Aayog

Dr. Anshu Bharadwaj
Programme Director, Green Transition, Energy & Climate Change Division, NITI Aayog

Sh. Rajnath Ram
Adviser, Energy, NITI Aayog

Core Modelling Team

Sh. Venugopal Mothkoor
Energy and Climate Modelling Specialist, NITI Aayog

Dr. Anjali Jain
Consultant, NITI Aayog

Sh. Nitin Bajpai
Consultant, NITI Aayog

Authors

NITI Aayog (Lead Authors)

Sh. Venugopal Mothkoor
Energy and Climate Modelling Specialist, NITI Aayog

Dr. Anjali Jain
Consultant, NITI Aayog

Sh. Nitin Bajpai
Consultant, NITI Aayog

Ms. Srishti Dewan
Young Professional, NITI Aayog

Knowledge Partners

Sh. Vaibhav Chaturvedi
Senior Fellow, CEEW

Ms. Pallavi Das
Programme Lead, CEEW

Sh. Anurag Dey
Programme Associate, CEEW

Ms. Chetna Arora
Programme Associate, CEEW

Sh. Zaid Ahsan Khan
Programme Associate, CEEW

Ms. Shruti Dayal
Senior Program Associate, Ex-WRI India

Ms. Jyoti Sharma
Senior Program Associate, WRI India

Ms. Meghana Munagala
Senior Program Associate, WRI India

Sh. Abhijit Namboothiri
Program Associate, WRI India

Sh. Abhishek Bhardwaj
Senior Program Associate, WRI India

Ms. Gowthami T S
Program Manager, WRI India

Sh. NGR Kartheek
Senior Program Manager, WRI India

Sh. Arpan Golechha
Program Manager, WRI India

Ms. Ashwini Hingne
Associate Director, WRI India

Peer Reviewers

Sh. Sharath Kumar Pallerla
Scientist G, Ministry of Environment, Forest and Climate Change (MoEFCC)

Sh. Ajay Raghava
Deputy Director, Ministry of Environment, Forest and Climate Change (MoEFCC)

Sh. Maimun Alam
Director, Ministry of Steel

Sh. Ravi Prajapati
Joint Director, BEE

Sh. Shikhar Jain
Executive Director, CII

Sh. Ravi Kumar
Consultant, NITI Aayog

Technical Editors

Sh. Nihar Gokhale
Communication Specialist (Independent)

Ms. Rishu Nigam
Communication Specialist (Independent)

Working Group Members

Sh. Jawahar Lal
Member Secretary of the Working Group, General Manager (Energy), NITI Aayog

Sh. Venugopal Mothkoor
Member Secretary of the Working Group, Energy and Climate Modelling Specialist, NITI Aayog

Dr. L. P. Singh
Director General, NCCBM

Dr. Neeraj Sinha,
Adviser/Scientist 'G', PSA

Sh. Ashwini Kumar
Economic Advisor, Ministry of Steel

Sh. Shri Deepak Mishra
Jt. Secretary, (Petrochemicals Division), Dept. of Chemicals and Petrochemicals

Ms. Sujata Sharma
Jt. Secretary (Marketing and Oil Refinery), MoPNG

Sh. Anandji Prasad
Advisor (P), Ministry of Coal

Sh. Ashok Kumar
Deputy Director General (DDG), BEE

Sh. Sharath Kumar Pallerla
Scientist G, Ministry of Environment, Forest and Climate Change (MoEFCC)

Sh. Vinamra Mishra
Director, MoMSME

Sh. Ajay Raghava
Deputy Director, Ministry of Environment, Forest and Climate Change (MoEFCC)

Sh. Gaurav Kishore Joshi
Deputy Secretary (Manufacturing Sector), Ministry of Heavy Industries

Sh. Bajrang Maheswari
Technical Consultant (Hydrogen & Decarbonisation Strategies), Ministry of Heavy Industries

Ms. Jyoti Mukul
Chief, Energy, CII

Sh. Hemant Mallya
Fellow, CEEW

Sh. Sobhanbabu PRK
Senior Fellow, TERI

Sh. Arpan Gupta
Director, FICCI

Sh. Sachin Kumar
Director, Shakti Sustainable Energy Foundation

Ms. Gunjan Jain
Research Executive, FICCI

Ms. Ekta Sharma
Research Executive, FICCI

Ms. Sarita Koli
Consultant, FICCI

Ms. Aditi Karki
Research Associate, FICCI

Sh. Sharvan Kr. Pushkar
Consultant, NITI Aayog (Co-ordinator)

Sh. Vishal Kumar
Young Professional, NITI Aayog (Co-ordinator)

Collaborators/ Expert Consultants

Ms. Prachi Priya
Assistant Vice President, Economic & Public Policy Research, Hindalco Industries Ltd

Sh. Himanshu Singh
Director (Strategy), Vedanta Ltd

Sh. Arvind Bodhankar
Head of Sustainability, AM/NS India

Sh. Deependra Kashiva
Director General, Sponge Iron Manufacturers Association

Sh. Prakash Tatia
Welspun Steel Ltd.

Sh. R K Goyal
Managing Director, Kalyani Steels Ltd

Sh. Deepak Bhatnagar
Secretary General, Pellet Manufacturers Association of India

Sh. Vijay Sharda
Chairman and Managing Director, Shabro Metals & Technologies

Sh. Anil Dhawan
Director General, Alloy Steel Producers Association of India

Sh. Rajeev Ranjan
GM (Business Planning), Steel Authority of India Ltd

Sh. Koustuv Kakati
Head Regulatory Affairs (Trade & Economy), Tata Steel Ltd

Sh. Sameer Singh
DGM - Sustainability, Jindal Stainless Ltd

Sh. V R Sharma
Vice Chairman, JSP Group Advisory Services

Sh. Prabodha Chandra Acharya
Chief Sustainability Officer, JSW Steel Ltd

Sh. Patel Sidhartha
Danieli India Ltd.

Sh. E R Raj Narayanan
Chief Manufacturing Officer, Ultra Tech Cement Ltd

Sh. Ravindra Jain
Dy. General Manager (E&I), JK Lakshmi Cement Ltd.

Sh. A.D. Saxena
Dy G M Geology, J K Lakshmi Cement Ltd

Sh. Yaswant Mishra
President (Corporate) and Chief Financial Officer, Mangalam Cement

Sh. Rajesh Deoliya
Senior Vice President, My Home Industries Pvt Ltd

Sh. Gajendra Pratap Singh
Joint President, Shree Cement Ltd

Sh. Narendra Singh
Chief Manufacturing Officer, Saurashtra Cement Ltd

Sh. Birinder Singh
Director (Corporate Services), IFFCO

Sh. Vipul Varshney
DGM - Projects, YARA International

Communication and Research & Networking Division, NITI Aayog

Ms. Anna Roy
Programme Director, Research & Networking

Sh. Yugal Kishore Joshi
Lead, Communication

Ms. Keerti Tiwari
Director, Communication

Dr. Banusri Velpandian
Senior Specialist, Research and Networking

Ms. Sonia Sachdeva Sharma
Consultant, Communication

Sh. Sanchit Jindal
Assistant Section Officer, Research and Networking

Sh. Souvik Chongder
Young Professional, Communication

NITI Design Team

NITI Maps & Charts Team

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List of Abbreviations

ACC	Advanced Chemistry Cell
ADEETIE	Assistance in Deploying Energy-Efficient Technologies in Industries and Establishments
BF-BOF	Blast Furnace–Basic Oxygen Furnace
BEE	Bureau of Energy Efficiency
BRSR	Business Responsibility and Sustainability Report
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture, Utilisation and Storage
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties
CPCB	Central Pollution Control Board
CPPRI	Central Pulp and Paper Research Institute
CPS	Current Policy Scenario
DC	Designated Consumer
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EE	Energy efficiency
EEFP	Energy Efficiency Financing Platform
ELVs	End-of-Life Vehicles
ESCO	Energy Service Company
ETS	Emissions Trading System
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GeM	Government e-Marketplace
GH_2	Green Hydrogen
GJ	Giga Joule

GoI	Government of India
Gt	Giga Tonne
H_2	Hydrogen
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IESS	India Energy Security Scenarios
IPCC	Intergovernmental Panel on Climate Change
IPMA	Indian Pulp and Paper Manufacturers Association
IREDA	Indian Renewable Energy Development Agency
ISO	International Organisation for Standardisation
kWh	Kilo Watt-Hour
LC3	Limestone Calcined Clay Cement
LTS	Long-Term strategy
MACC	Marginal Abatement Cost Curve
MDBS	Multilateral Development Banks
MoMSME	Ministry of Micro, Small and Medium Enterprises
MNRE	Ministry of New and Renewable Energy
MoEFCC	Ministry of Environment, Forest and Climate Change
MoP	Ministry of Power
MoPNG	Ministry of Petroleum and Natural Gas
MoRTH	Ministry of Road Transport and Highways
MoS	Ministry of Steel
MSME	Micro, Small and Medium Enterprises
Mt	Million Tonnes
N_2O	Nitrous Oxide
NDC	Nationally Determined Contribution
Net Zero	A state in which anthropogenic greenhouse gas emissions are balanced by removals over a specified period
NZ / NZS	Net Zero / Net Zero Scenario
OPEX	Operating expenditure
PAT	Perform, Achieve and Trade
PLI	Production-Linked Incentive
PPP	Public–Private Partnership
R&D	Research and Development
RCO	Renewable Consumption Obligation
RE	Renewable Energy

RESCO	Renewable Energy Service Company
RFNBO	Renewable Fuels of Non-Biological Origin
SAF	Sustainable Aviation Fuel
Scope 1	Direct GHG emissions from owned/controlled sources
Scope 2	Indirect GHG emissions from purchased electricity/steam/heat/cooling
Scope 3	All other indirect emissions in a value chain
SECs / ESCerts	Energy Saving Certificates (under PAT)
SIDBI	Small Industries Development Bank of India
SMR	Small Modular Reactor
T&D	Transmission and Distribution
TIMES	The Integrated MARKAL EFOM System
TOE	Tonne of Oil Equivalent
UNFCCC	United Nations Framework Convention on Climate Change
ZED	Zero Defect Zero Effect (MSME certification/programme)

Executive Summary

India has set twin goals of becoming a developed, high-income economy by 2047 and achieving Net Zero emissions by 2070. The industrial sector is at the heart of this effort, as it is a key driver of economic growth and a major source of greenhouse gas (GHG) emissions. Industrial growth will surge, as India's GDP moves toward a projected USD 30 trillion by 2047 as demand for steel, cement, chemicals and other materials will increase many times, leading to increased energy use. Industry sector accounts for nearly 24% of India's total GHG emissions (excluding emissions from electricity use) in 2020. Major emitters in this sector include steel, cement and aluminium (the largest contributors), followed by chemicals, fertilisers, and other manufacturing. Decoupling industrial growth from carbon emissions is imperative for "green growth," yet this transition poses a significant challenge given the reliance on fossil fuels for around 83% of industrial energy.

Modelling Approach

It is in this context, NITI Aayog's Inter-Ministerial Working Group, constituted for industrial sector has delved into various facets of industrial energy transition including industrial output, energy demand across major subsectors: steel, cement, aluminium, textiles, petrochemicals, paper & pulp, fertilisers, refinery, chlor-alkali and other manufacturing. The comprehensive framework adopted for modelling industrial sector adopts two scenarios: Current Policy Scenario (CPS) and Net Zero Scenario (NZS), within which the goal of becoming developed economy has been kept sacrosanct. The framework integrates granular data on technology options, fuel choices, and material efficiency, while reflecting on-going national programmes such as the National Green Hydrogen Mission, renewable energy expansion, and green industrial initiatives.

The modelling of industrial sector is carried out using in-house models India Energy Security Scenarios (IESS) and TIMES (The Integrated MARKAL-EFOM System) for sectoral activity projections, fuel switching pathways, and emissions reduction strategies to 2070.

Key Modelling Insights

Multi-fold Industrial Demand Growth Aligned with Viksit Bharat

India's industrial commodity demand is set to rise multi-fold as urbanisation, infrastructure build-out, housing, and manufacturing at a scale. By mid-century, India's per-capita use approaches levels seen in today's developed economies. As incomes rise toward high-income economy levels (around USD 18,000+), per-capita use is projected to converge toward high-income norms, reaching ~356 kg steel, ~921 kg cement, and ~16 kg aluminium by 2050. While the per capita use increases, the objective is not to maximise consumption, instead to meet needs sustainably and resource-efficiently. Major transition levers of the industry sector's low-carbon transition will include electrification of industrial processes, efficiency aligned with international best standards, non-fossil fuel-based captive power, improvements in material efficiency and recycling, and increased use of biomass and green hydrogen.

Energy mix transforms decisively from fossil to clean sources.

Under Current Policy Scenario, fossil fuels remain the dominant energy source with 72% share by mid-century, and 52% by 2070 (vs 83% in 2025). Under Net Zero Scenario, the energy mix shifts fundamentally, electrification driven by non-fossil power increases from 16% in 2025 to 55% by 2070. Green hydrogen emerges as a critical fuel for low-carbon transition in steel, refineries and fertilisers, rising from low-base today to 42 Mt by 2070 in Net Zero Scenario. Biomass and waste heat recovery also play a crucial role in industrial low-carbon transition. By 2070, fossil share declines to 26% in Net Zero Scenario, and the residual fossil capacity largely operates with Carbon Capture Utilisation and Storage (CCUS).

Circular economy and material efficiency unlock significant abatement.

Under the enabling conditions for circular economy, in Net Zero Scenario, steel scrap utilisation increases from 22% to 30% by 2050 and 40% by 2070, thereby reducing reliance on energy-intensive ore-based smelting processes. Also, in cement, clinker ratio is expected to lower from 0.67 in 2024 to 0.55 by 2070 with higher use of supplementary cementitious materials (slag, calcined clay, pozzolans), avoiding nearly 50-100 Mt of clinker annually during 2050-70. Aluminium recycling serves 40% of 2070 demand while using just 5% of the energy of primary production. These circular measures decouple growth from raw-material use and emissions.

Technology transition is central to emissions reduction.

Industrial low-carbon transition depends heavily on technologies that are still emerging or not yet commercial at scale. The study finds that half of the emissions reductions rely on technologies currently not available at scale such as Green Hydrogen, CCUS, Small Modular Reactors (SMRs) and high cost electrification solutions such as electricity boilers or Heat pumps. Many of these solutions are in pilot or demonstration phases today. India is actively exploring these frontiers through the National Green Hydrogen Mission, which targets 5 Mt of production by 2030; adoption of new cement blends like Limestone Calcined Clay Cement (LC3), which can cut cement process CO_2 emissions by 40%; launch of five industrial CCUS test beds in the cement sector in 2025; and plans to deploy SMRs to supply clean process heat and power for industry.

Indicator Snapshot

Table E1: Current Policy Scenario vs Net Zero Scenario – 2050 & 2070

Indicator		Current Policy Scenario		Net Zero Scenario	
		2050	2070	2050	2070
Industrial Output	Steel (million tonnes)	624	821	624	821
	Cement (million tonnes)	1592	1985	1592	1985
	Aluminium (million tonnes)	28	38	28	38
Circularity	Steel - Scrap Utilisation (%)	20%	20%	30%	40%
	Cement - Clinker Ratio	0.65	0.6	0.62	0.55
	Aluminium - Scrap Utilisation (%)	30%	30%	36%	40%
Industrial Energy Demand (Mtoe)		980	1150	890	980
Fossil Use (Mtoe/%)		700/72%	700/61%	460/52%	250/26%
Electricity Use (Mtoe/%)		231/24%	340/29%	330/37%	540/55%
Green Hydrogen (million tonnes)		8.5	24	22	42
CCUS Deployment (MtCO$_2$e/yr)		Nil		Low	~1,000
Investment Requirement (2026–2070, USD trillion)*		USD 4.5 trillion		USD 6.1 trillion	

**Refer IMWG report on Financing Needs (Vol. 9) for investment requirements*

Priority Challenges and Policy Suggestions

While low-carbon transition in industry is technically feasible, achieving Net Zero depends on technologies still emerging or not yet commercial at scale. The transition faces several systemic barriers that could raise transition costs, prolong fossil fuel dependence, and delay socio-economic gains. India's industrial low-carbon transition rests on four structural pillars: Energy Efficiency, Circularity, Electrification, and Clean Fuels & Technologies, supported by an enabling ecosystem of finance and skilled labour.

1. Energy efficiency barriers

Energy efficiency is fundamental to low-carbon transition; the International Energy Agency (IEA) labels it the "first fuel", yet global efficiency improved by just 1% in 2024. India's Perform, Achieve and Trade (PAT) scheme covers 1,333 entities and achieved 8% annual energy savings, but critical barriers still persist.

Key Barriers: Weak performance monitoring (3-year audit cycle too infrequent), absence of uniform benchmarks for thermal processes, limited access to affordable finance for Micro, Small and Medium Enterprises (MSMEs), prevalence of outdated technologies (inefficient motors, coal-fired boilers), and significant waste heat being vented instead of recovered.

Policy Suggestions:

- i. **Energy Performance monitoring**
    - a. Shift to continuous digital verification using Internet of Things (IoT) and Artificial Intelligence (AI) with ISO 50001 standardisation
    - b. Enhance Bureau of Energy Efficiency (BEE's) benchmarking portal
- ii. **Financing and Technology modernisation**
    - a. Scale Assistance in Deploying Energy Efficient Technologies in Industries & Establishments (ADEETIEs) through interest subvention
    - b. Institutionalise Energy Service Company (ESCO) models in key clusters
    - c. Treat waste heat recovery as renewable
    - d. Promote heat pumps for low-temperature applications through viability gap funding

2. Circular economy and material recovery

Strong reliance on virgin materials drives resource depletion and emissions. India's circular economy is expected to reach USD 2 trillion and create 10 million jobs by 2050.

Key Barriers: Low quality of recycled materials, feedstock inconsistency, logistical fragmentation (transport costs outweigh material value), multiple regulatory layers, limited domestic scrap (India imported 8.69 Mt ferrous scrap in 2024), global export restrictions and import dependency on waste processing equipment.

Policy Suggestions:

- i. **Creating demand for circularity**
    - a. Introduce rigorous Bureau of Indian Standards (BIS) grading standards
    - b. Notify Green Public Procurement norms
    - c. Enable Digital Product Passports for traceability
    - d. Expand Extended Producer Responsibility (EPR) to further products and material (e.g. textiles, footwear, etc.)
    - e. Introduction of minimum recycled content guidelines for key sectors
- ii. **Waste Management**
    - a. Promote aggregation platforms and waste exchange clusters
    - b. Establish decentralised sorting and pre-processing centres through PPP model
    - c. Promote unified waste license system via digital single-window
    - d. Prioritise domestic waste equipment manufacturing
    - e. Formalise informal workers via verified IDs and training
- iii. **Import dependency on scrap**
    - a. Rationalise GST and import duties, favouring recycling
    - b. Promote advance sorting technologies (shredders, zorba, optical sorters).

3. Industrial electrification

Industrial electrification is 16% in 2025 with huge potential to scale. Replacement of fossil-fuel heat with electric alternatives will not only result in lower emissions but also strengthen competitiveness.

Key Barriers: High electricity costs (due to cross-subsidies for domestic use), reliability constraints (frequent outages force reliance on captive coal plants), technology gaps (electricity-based high-temperature processes still nascent), skill shortages in EPC and O&M, and high upfront capital costs for MSMEs.

Policy Suggestions:

- **i. Ensuring affordable and reliable electricity**
  - a. Rationalise power tariffs reflecting true costs
  - b. Enforce Time-of-Day pricing
  - c. Facilitate open-access approvals
  - d. Scale Renewable Energy Service Company (RESCO) models aggregating demand
  - e. Deploy Firm Dispatchable Renewable Energy contracts
  - f. Establish dedicated industrial power feeders for assured 24×7 supply
- **ii. Technology Readiness and Financing**
  - a. Develop sectoral electrification roadmaps linking temperature ranges to technologies
  - b. Provide blended finance for mature electric technologies
  - c. Include heat pumps and electric boilers in the National Manufacturing Mission

4. New technologies and fuels

Hard-to-abate sectors rely on technologies (Green Hydrogen Direct Reduced Iron (GH_2-DRI), electric crackers, CCUS), fuels (green hydrogen), and materials (LC3, inert anodes), that are still at nascent stages. High costs, limited raw materials, fragmented policies, and weak standardisation hinder investment.

Key Barriers: High technology risks and costs (first-of-a-kind projects face uncertain returns), limited raw materials (LC3 constrained by poor clay availability), financing constraints, lack of product taxonomy, weak R&D ecosystem with poor industry-academia linkages, critical mineral supply risks (Ni, Li, Co, PGMs).

Policy Suggestions:

- **i. Scale development and deployment of new fuels**
  - a. Government and MDBs to support pilot projects in H_2-DRI, inert anodes, CCUS
  - b. Create assured offtake platforms such as Sustainable Aviation, Maritime, Steel Buyers Alliances leveraging Article 6.2/6.4
  - c. Strengthen climate taxonomies to explicitly include all low-carbon process routes/technologies, with clear benchmarks, and thresholds
  - d. Government and industry bodies to roll out Type III eco-labels and rating systems for key materials
  - e. Provide Viability Gap Funding and deploy blended finance for technologies which have high upfront costs and risks
- **ii. Domestic Manufacturing and R&D Ecosystem**
  - a. Scale up Production Linked Incentive (PLI) schemes to cover the full value chain of clean technologies
  - b. Establish R&D centres of excellence with joint ventures between domestic firms, global providers, and research institutions

iii. Domestic Manufacturing and R&D Ecosystem

a. Identify and create calcined clay clusters to secure raw material supply
b. Strengthen the supply chain for biomass pellets/briquettes through aggregator incentives and storage infrastructure
c. Secure long-term international offtake agreements for critical minerals

5. Employment, skills, and trade competitiveness

Industrial low-carbon transition requires a skilled workforce and adaptive trade strategy against emerging global trade regulations including on carbon.

Key Barriers: Skill shortage and job displacement risks in affected regions and sectors, impact of European Union's Carbon Border Adjustment Mechanism (CBAM) on Indian steel/aluminium exports, protective tariffs on input materials, and lack of green export branding.

Policy Suggestions:

i. Employment:

a. Institutionalise Sector Skill Council (SSC)-industry collaboration for continuous curriculum updates and strengthening certification systems through employer-led assessments
b. Emphasise on-the-job training in emerging technologies
c. Develop transition skill roadmaps
d. Establish national skills intelligence system
e. Create a worker retraining policy with relocation support and district economic diversification frameworks

ii. Trade:

a. Accelerate low-carbon transition in export sectors
b. Institutionalise periodic tariff stocktakes
c. Launch "Green Stamp" initiative showcasing environmental footprint
d. Develop standardised and interoperable Life Cycle Assessment (LCA) frameworks and implement digital product passports

Conclusion

Industrial low-carbon transition represents both a critical challenge and an opportunity. As India pursues developed-nation status, its industrial sector transition requires success in technology upgrades, electrification, renewable adoption, resource efficiency, innovative financing, supportive policies, stronger institutional frameworks, and capacity-building across energy-intensive and MSME segments. This transformation can position India as a global leader in sustainable industrialisation, driving competitiveness, creating green jobs, and aligning growth with climate commitments.

1

INTRODUCTION

1

Introduction

India is embarking on a historic development journey to achieve the twin objectives of becoming a developed economy (Viksit Bharat by 2047) and achieving Net Zero emissions by 2070. The industrial sector lies at the heart of this transformation, serving as a cornerstone of economic growth while also representing one of the largest sources of Greenhouse Gas (GHG) emissions.

As industrialisation, urbanisation, and rising living standards reshape India's economy, demand for materials and energy will increase sharply. With GDP projected to reach USD 30 trillion (current prices) by 2047, the output of steel, cement, chemicals, and other industrial products is expected to multiply. Meeting this demand in a manner consistent with Net Zero goals requires a fundamental shift towards affordable, reliable and low-carbon energy sources, while simultaneously safeguarding energy security, employment, and social outcomes. India views this transformation as an opportunity to reshape its industrial landscape. The Honourable Prime Minister has characterised this moment as a "green industrial revolution", emphasising the potential for low-carbon technologies to drive competitiveness and job creation. India has assumed a leadership role internationally, co-chairing the Leadership Group for Industry Transition (LeadIT) alongside Sweden to advance the decarbonisation of heavy industries. Domestic initiatives such as Make in India and related programmes are strengthening clean-energy manufacturing capabilities, positioning India as an integral part of global value chains (GVCs) while meeting domestic demand.

A Legacy of Industrial Strength

Historically, India was a major industrial and trading powerhouse. Before colonial disruptions, the country accounted for roughly a quarter of global textile manufacturing, renowned for fine cotton and silk clothed markets worldwide. Indian metallurgy was equally distinguished: wootz steel, widely regarded as the finest in the world in 12th-century records, was exported globally for weapon-making. India was also a maritime leader. By the 18th century, shipyards in Surat, Bombay, and Calicut were reportedly constructing up to 40% of the world's ships, reflecting early integration into global trade and technological networks (Scammell, 2000).

This industrial dominance gradually eroded as colonial policies reshaped production systems and trade relationships. Over the past few decades, however, a series of structural reforms, including the Goods and Services Tax (GST), Production Linked Incentive (PLI) schemes, the Make in India, Startup India, and the National Industrial Corridor Development Programme, have supported India's re-emergence as a significant global industrial player. India is now the world's second-largest producer of cement, steel and aluminium with cement efficiency being among the best globally. It is also the second-largest importer of scrap steel, reflecting a growing emphasis on recycling and reduced reliance on virgin iron ore. Across sectors, manufacturers are increasingly embracing sustainability, with some firms leading global rankings in environmental, social and governance (ESG) performance. These strengths position the Indian industry to leapfrog towards low-carbon development pathways.

Emissions and Energy

Industry is the largest end-use energy-consuming sector in India. More than 80% of industrial energy demand is met by fossil fuels—coal, oil, and natural gas—while electrification remains limited at around 16%, below the national average of 21% (estimated). Coal is extensively used in iron and steel production (as coke in blast furnaces), cement manufacturing (as kiln fuel), and chemical industries. Natural gas plays a critical role in fertiliser production, both as feedstock for ammonia and as a fuel, and is also used in ceramics and glass manufacturing.

This fossil fuel-intensive profile results in substantial CO_2 emissions. According to India's Fourth Biennial Update Report (2024), manufacturing industries and emissions from Industrial, Processes and Product Use (IPPU) together account for around 24% of gross Greenhouse Gas (GHG) emissions, excluding emissions from electricity use. Steel and cement are the largest contributors, followed by aluminium, chemicals, and fertilisers.

Green Technologies and Transition Opportunities

Enabling a low-carbon transition in India's industrial sector will require unprecedented levels of technological adoption and innovation. Several critical technologies, such as Green Hydrogen, Carbon Capture, Utilisation, and Storage (CCUS), electrification of industrial processes, and Small Modular Reactors (SMRs), are yet to achieve commercial maturity, and India is actively exploring these pathways. The central challenge is to reduce cost and scale these solutions from pilot and demonstration stages to mass deployment. Doing so will require supportive policies, access to finance, and enabling infrastructure such as hydrogen pipelines, CO_2 transport networks, and grid upgrades.

Indian industry has begun to engage with this transition. More than 127 Indian companies have committed to Net Zero targets under the Science Based Targets initiative (SBTi), placing India sixth globally in terms of corporate climate commitments. However, participation among heavy industrial sectors remains limited: fewer than 10% of major firms in sectors such as power, steel, and cement have adopted Net Zero targets to date (Seneca ESG, 2024).

Regulatory measures are accelerating momentum. The Securities and Exchange Board of India (SEBI) now requires the top 1,000 listed companies to disclose Environmental, Social, and Governance (ESG) metrics under the Business Responsibility and Sustainability Report (BRSR) framework, including emissions, climate risks, and mitigation efforts. This has strengthened transparency and accountability. International developments are also shaping incentives. The European Union's (EU's) Carbon Border Adjustment Mechanism (CBAM) applies a carbon price to imports of steel, cement, aluminium, and other carbon-intensive products. While such measures underscore the growing importance of emission intensity reduction, they also raise concerns about unilateral trade actions that may disproportionately affect developing countries with limited historical responsibility for climate change.

Mission LiFE and Societal Engagement

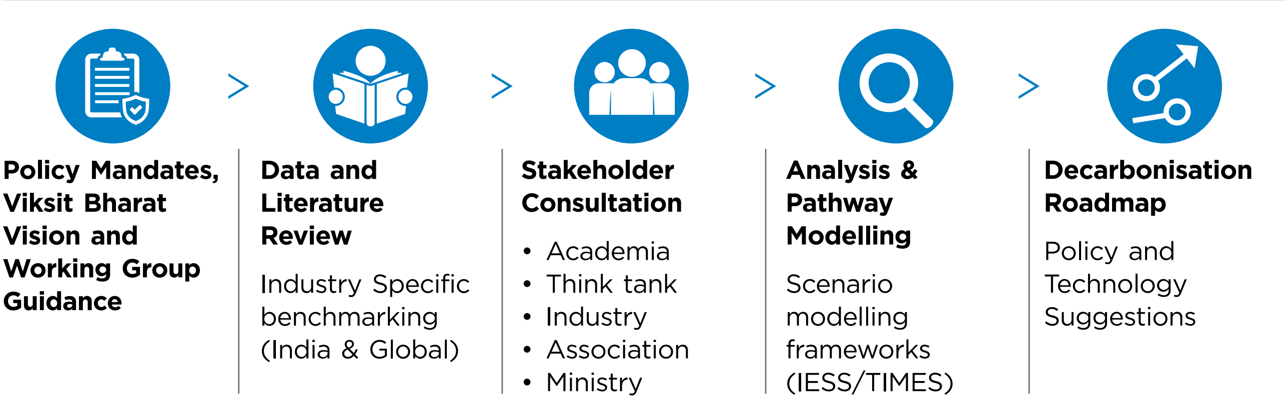
India's climate strategy extends beyond industry to a people-centric movement. Mission LiFE (Lifestyle for Environment), launched by the Honourable Prime Minister in 2022, calls for large-scale behavioural change toward sustainable production and consumption. In the industrial context, Mission LiFE promotes demand for sustainable products, reinforcing the incentive for firms to manufacture green goods—from eco-labelled textiles to low-carbon cement (MoEFCC, 2022).

Digital public infrastructure is supporting this transition. The India Energy Stack, currently under development, is envisaged as an open digital backbone that will support smart grids, electric vehicle integration, and real-time energy management. Much as the Unified Payments Interface (UPI) transformed digital finance, the energy data stack is expected to unlock innovation and transparency in energy use, empowering industries and consumers alike to optimise efficiency and integrate renewable energy at scale.

With its growing economic influence, India has the opportunity to demonstrate a distinctive model of "green growth" —one in which industrial expansion aligns with climate stewardship. An emphasis on quality, innovation, affordability, and sustainability can position India as a preferred supplier for climate-conscious global markets. By investing in cleaner technologies and adopting global best practices, India aims to emerge as a trusted and responsible production hub, delivering on the twin goals of prosperity and planetary well-being. Achieving Net Zero by 2070 is a formidable task, but with strategic planning, international collaboration through technology sharing and affordable finance, and broad participation from government, industry, and communities, India's industrial transition can set a benchmark for emerging economies.

Institutional Mechanism: Inter-Ministerial Working Group on Industry

The Inter-Ministerial Working Group on Industry is one of the ten working groups constituted by NITI Aayog to develop a long-term development vision aligned with India's commitment to becoming a developed nation by 2047 and to achieve Net Zero emissions by 2070. Collectively, these groups examine macroeconomic dimensions of the transition, sectoral implications across industry, transport, power, buildings, and agriculture, requirements for climate finance and critical minerals, and the social implications of the Net Zero pathway (Figure: 1.1).



Policy Mandates, Viksit Bharat Vision and Working Group Guidance

>

Data and Literature Review

Industry Specific benchmarking (India & Global)

>

Stakeholder Consultation

- Academia
- Think tank
- Industry
- Association
- Ministry

>

Analysis & Pathway Modelling

Scenario modelling frameworks (IESS/TIMES)

>

Decarbonisation Roadmap

Policy and Technology Suggestions

Figure 1.1: Approach for developing the Net Zero Pathway

The Inter-Ministerial Working Group on Industry was mandated to assess the current state and long-term evolution of India's industrial ecosystem, covering energy use, emissions intensity, technology maturity, and investment requirements, and to suggest a comprehensive transition pathway through 2070. To address these objectives, a structured and collaborative roadmap development process was adopted.

Composition of the Working Group:

Chair: Dr. V.K. Saraswat, Member, NITI Aayog

Representatives from Ministries/Departments: Steel, Coal, Power, New & Renewable Energy, Petroleum & Natural Gas, Chemicals & Fertilisers, Heavy Industries, Micro, Small & Medium Enterprises, Mines, Commerce & Industry, Environment, Forest and Climate Change.

Key institutions: Bureau of Energy Efficiency (BEE) selected central public sector enterprises, and technical institutions in steel, cement, power, fertilisers, and other energy-intensive industries.

Industry and knowledge partners: Industry associations and sector platforms, along with leading think tanks and research organisations working on industrial low-carbon transition, technology pathways, energy systems modelling, and climate policy.

Stakeholder consultations across individual subsectors provided valuable insights into the deployment of low-carbon technologies, including adoption requirements, key challenges and opportunities, and the role of research and development in reducing costs, accelerating uptake, and improving efficiency. Common themes emerged across these consultations, including sector-specific needs and opportunities, the applicability of decarbonisation pillars, and the technological advancements required to support long-term emission reduction goals.

The Terms of Reference (ToR) of the Inter-Ministerial Working Group on Industry include the following:

i. Examine the potential of growth across industrial sub-sectors, including energy consumption implications, in line with GDP growth and structural economic shifts.
ii. Examine the role of energy efficiency improvements and technology shifts across industrial sub-sectors.
iii. Examine the impact of shifts to cleaner and alternative fuels and demand-side electrification on emissions, energy consumption, and energy security, particularly in hard-to-abate sectors.
iv. Assess the potential of circular economy and resource efficiency to reduce demand for virgin materials.
v. Assess the potential of CCUS in industrial decarbonisation, particularly in hard-to-abate sectors.
vi. Examine industrial competitiveness in the context of global developments such as the Carbon Border Adjustment Mechanism (CBAM).
vii. Examine transition risks faced by micro, small and medium enterprises (MSMEs).
viii. Analyse sources of finance and financing instruments for industrial low-carbon transition.

2

LANDSCAPE OF THE INDUSTRY SECTOR IN INDIA

Landscape of the Industry Sector in India

2

India stands at a strategic crossroads in the evolving global industrial landscape. Geopolitical shifts, the restructuring of global value chains (GVCs), and a global push toward sustainability are driving demand for resilient, diversified, and low-carbon manufacturing hubs. India is well-positioned to respond, leveraging its large and young workforce, with over 60% of the population in the working-age bracket, an expanding domestic market, and a competitive manufacturing base (MoSPI, 2022). Government initiatives such as Make in India, Production Linked Incentive (PLI) schemes, and infrastructure modernisation have further strengthened the country's industrial competitiveness (IBEF, 2024).

India's industrial sector is not only a critical engine of domestic economic growth, but also increasingly embedded in global supply chains across automotive, electronics, pharmaceuticals, and textiles sectors. As global economies accelerate their transition to Net Zero, the next phase of industrial development will be defined by innovation, low-carbon transition, and efficient use of resources.

This presents a dual opportunity for Indian industry: (i) to expand its global economic footprint while leading the transition to sustainable, resource-efficient industrial practices, (ii) rising global demand for low-carbon products, circular economy models, and green technologies offers strong incentives to adopt clean energy, invest in green manufacturing to enhance efficiency. With the right policy alignment and institutional support, India can emerge as a global leader of the green industrial revolution, building an economy that is competitive, environmentally responsible, and aligned with the long-term sustainability goals.

This chapter is structured in three segments. The first segment situates Indian industry in the global context, outlining its economic contribution, production trends, and emissions footprint. The second segment presents detailed sectoral deep dives across key industrial sub-sectors. The final segment explores the major decarbonisation levers shaping the industry's transition toward a low-carbon future.

2.1 INDIAN INDUSTRY AND GLOBAL CONTEXT

Globally, industry contributed about 27% to GDP and employed 24% of the workforce in 2021 (World Bank, 2023; 2025) (see Figure 2.1). In the same year, China stood out with 38% of its GDP and 32% of employment attributed to industry, while South Korea and Japan also reported higher than the world average contributions of the industrial sector to their economies. In comparison, in the US and the EU, about 18–22% of GDP and 19–25% of employment came from industries (World Bank, 2025). In India, the industrial sector contributed 27% to its Gross Value Added (GVA) and employed about 24% of the workforce in 2021 (MoSPI, 2025; World Bank, 2023). Within this, manufacturing accounted for 56.2%, construction 27.3%, utilities 10%, and mining and quarrying 6.5% (MoSPI, 2025).

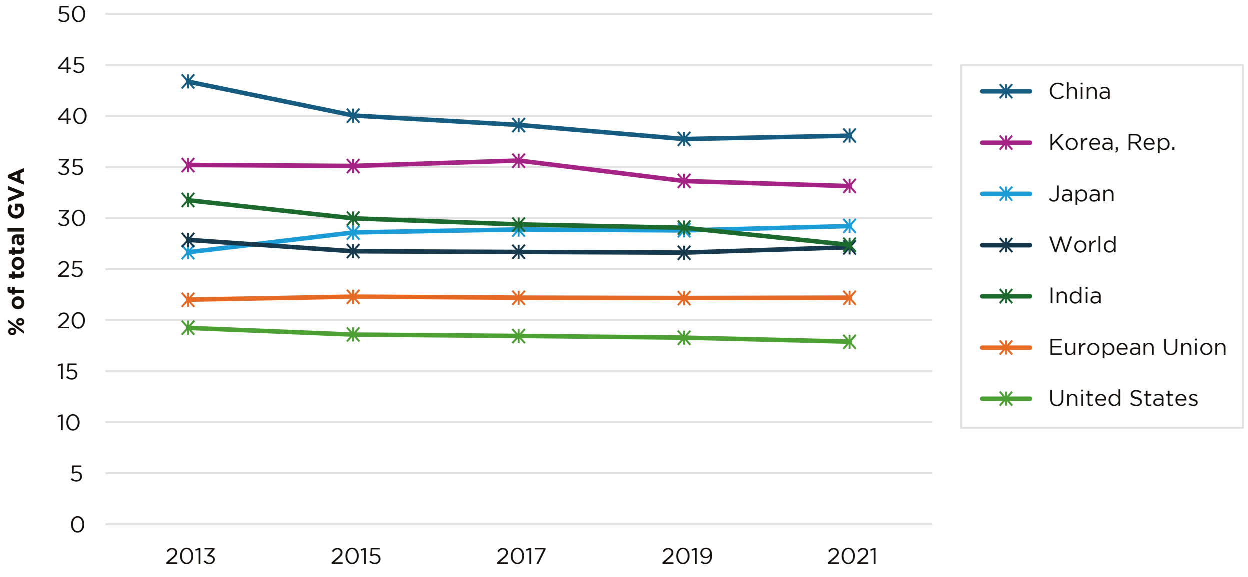


Figure 2.1: Industry (including construction), value added (% of total GVA)

Source: *(World Bank, 2023)*

2.1.1 Industrial Output: Sectoral Strengths

India is steadily emerging as a key player in global industrial production, especially in the steel, cement, aluminium and chemical sectors. These industries form the backbone of India's manufacturing economy, significantly contributing to GDP and exports (WSA, 2024; IBEF, 2025). India is currently the world's sixth-largest chemicals producer and ranks second after China in steel, cement and aluminium output, accounting for nearly 6% of aluminium, 8% of steel and over 10% of cement supply globally (WSA, 2024; GCCA & TERI, 2025).

India's advantages lie in cost-efficient labour, abundant raw materials, and strong domestic demand driven by urbanisation and infrastructure development. Pharmaceutical exports, especially generics have underpinned growth in the chemicals sector. Foreign Direct Investment (FDI) attracted under the Make in India initiative has further strengthened capacity across these areas (Sharma, 2024).

India experienced significant growth in industrial production between 2000 and 2020 (Figures 2.2 and 2.3). While China remained dominant, producing 61% of steel, 57% of aluminium, 52% of cement, and 45% of chemicals globally (WEF, 2023), India's production grew steadily even as output in G7 countries plateaued (OECD, 2022).

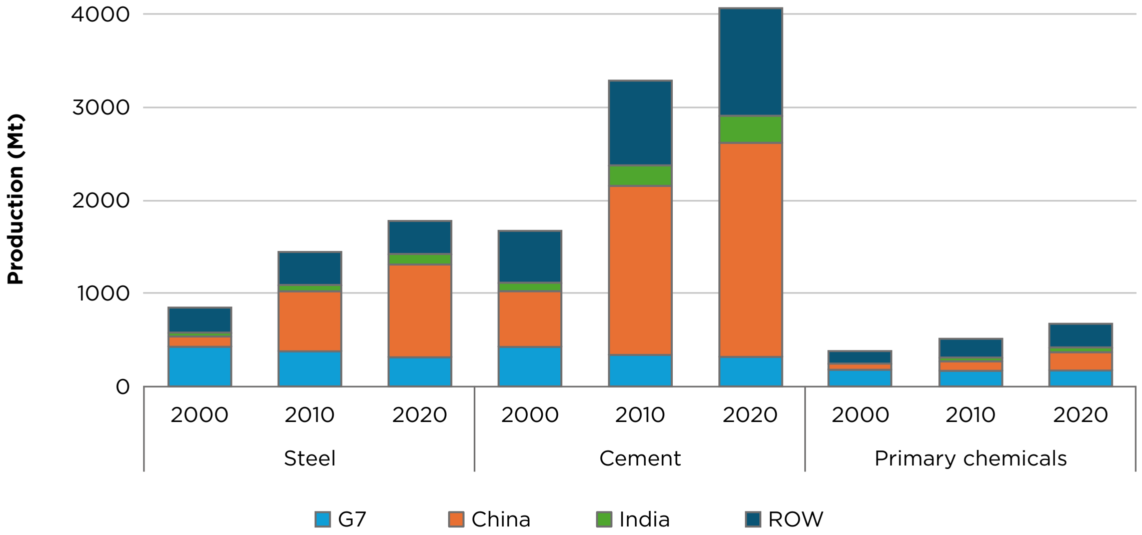


Figure 2.2: Materials production of G7 members in the context of global production (million tonnes)

Source: *(IEA, 2022)*

Note: ROW = Rest of the World;
The total production of ammonia, methanol, ethylene, propylene, benzene, toluene and mixed xylenes.

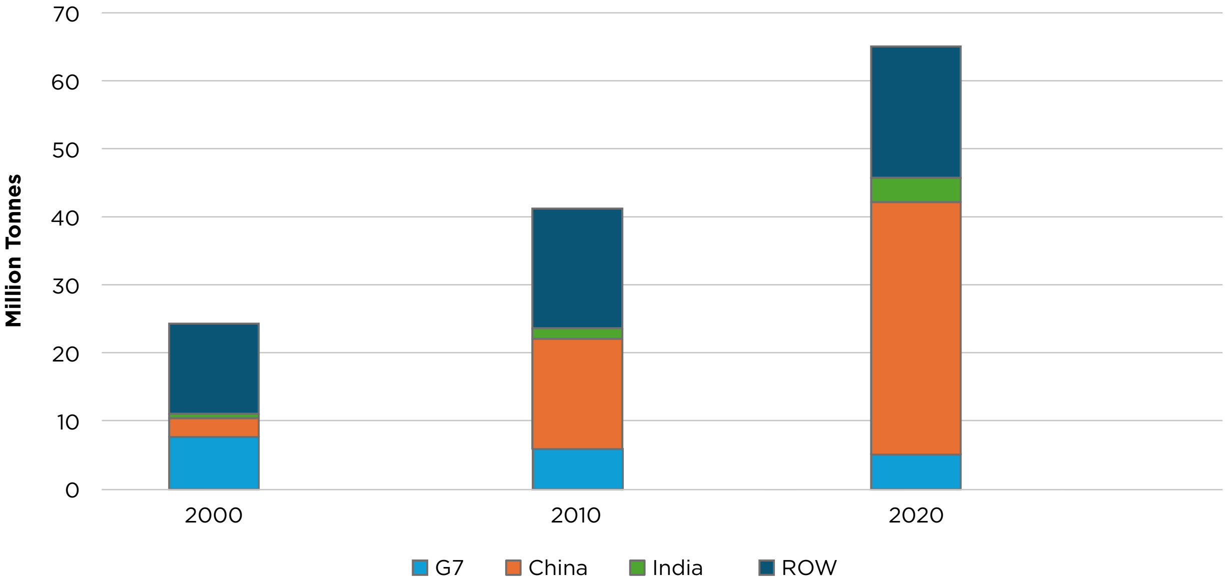


Figure 2.3: Aluminium production of G7 members in the context of global production (million tonnes)

Note: *ROW = Rest of the World;*

Source: *(IEA, 2022); (IAI, 2024; NITI Aayog, 2023); (IAI, 2025)*

Looking ahead, the global demand for steel, cement, aluminium and chemicals is projected to increase by 12-30% by 2050, largely from emerging markets (IEA, 2021). India has a strategic opportunity to scale sustainably and enhance its role in global value chains.

2.1.2 Energy and Emissions Profile

The industrial sector is a major source of greenhouse gas (GHG) emissions. In 2023, it accounted for 21.54% of global direct emissions from energy use and industrial processes, with steel, cement, and chemicals comprising nearly 71% of this (UNIDO, 2024) (see Figure 2.4 and Table 2.1).

Table 2.1: Global and industrial GHG emissions (million tonnes of CO_2 equivalent)

	1990	1995	2000	2005	2010	2015	2020	2023
Industry	5974	6215	6404	8097	9746	10483	11026	11408
Global Total	32726	33930	36175	41296	45814	48808	49327	52962
Share of Industry	18.26%	18.32%	17.70%	19.61%	21.27%	21.48%	22.35%	21.54%

Source: *(UNIDO, 2024)*

India's industrial emissions profile reflects high material intensity. Roughly 67% of emissions were from energy use and the balance from processes (MoEFCC, 2024).

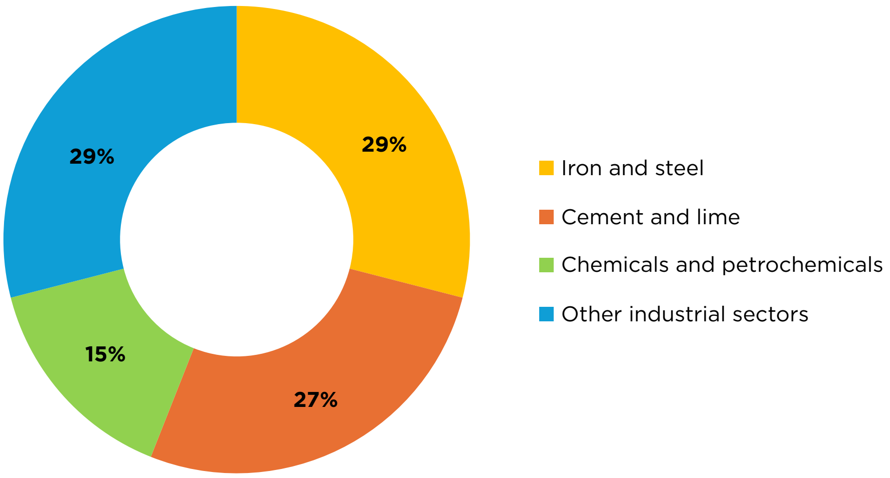


Figure 2.4: Contribution of industry sub-sector emissions in 2022 (Globally)

Source: *(UNIDO, 2024)*

Heavy industries, particularly steel, chemicals, cement, non-ferrous metals, and paper account for the vast majority of industrial energy use. As India's economy grows, both output and energy use are expected to rise substantially. Global forecasts estimate that industrial energy demand could more than double by 2050, especially in emerging economies (US EIA, 2021). Managing this growth while cutting emissions is crucial for India's low-carbon pathway.

2.1.3 Lessons from Global Industrial Trends

India's trajectory parallels global trends in which countries are simultaneously pursuing industrial growth, technology upgrades, and emissions reductions, as detailed below:

- **European Union:** Industry remains a top emitter even though emissions fell 29% from 1990 to 2022 (Eurostat, 2025). Tools like the Emissions Trading Scheme (ETS), Carbon Border Adjustment Mechanism (CBAM), and Renewable Energy Directive (RED) are implemented to drive low-carbon transition.
- **United States:** Industrial policy emphasises reshoring and manufacturing investment. While the Inflation Reduction Act (IRA), Bipartisan Infrastructure Law (BIL), and CHIPS Act previously allocated significant funds, President Trump's 2025 administration has sought to repeal IRA climate provisions and redirect CHIPS subsidies toward domestic semiconductor production over green industrial decarbonisation (Carlsen & Gangotra, 2024).
- **Japan:** Focuses on high-tech and automotive sectors. The 2021 Green Growth Strategy and USD 110 billion (15 trillion yen) Green Innovation Fund support research and development (R&D) in hydrogen, carbon recycling, and energy storage (JETRO, 2024).
- **South Korea:** With manufacturing at 39% of GDP in 2017, Korea emphasises energy efficiency, circular economy, and smart factories. Its low-carbon roadmap features CCUS and Industry 4.0 (Government of the Republic of Korea, 2020).

India shares the global industrial challenges of rising energy demand, emissions intensity, and green technology integration. But it also holds a distinct opportunity to shape its transformation early by leveraging PLI schemes and transition platforms to achieve sustainable competitiveness.

2.2 SECTORAL DEEP DIVES: INDUSTRY IN THE INDIAN AND GLOBAL CONTEXT

This section gives details for the selected sectors, India's comparative position with global averages and other countries in terms of production, consumption, per capita consumption, emissions and sectoral policies for key sectors including steel, cement, aluminium, fertiliser, and textiles. Less energy intensive sectors like paper and pulp, chlor-alkali, ethylene, refineries, and MSMEs, are discussed in the Indian context.

2.2.1 Steel sector

Global Context

The global steel industry has expanded rapidly over the past few decades, led by China and India. Global crude steel production rose from 770 million tonnes (Mt) in 1990 to 1,892 Mt in 2023 (WSA, 2024) (see Figure 2.5). The Blast Furnace, Basic Oxygen Furnace (BF–BOF) and Electric Arc Furnace (EAF) processes account for approximately 71% and 29% of global production, respectively (WSA 2024). The top five producers are China, India, Japan, the USA, and Russia. Future growth is expected from emerging economies in Africa, South and East Asia, including India, and Latin America, as demand plateaus or declines in regions such as Europe, Japan, the USA, and South Korea (WSA, 2024).

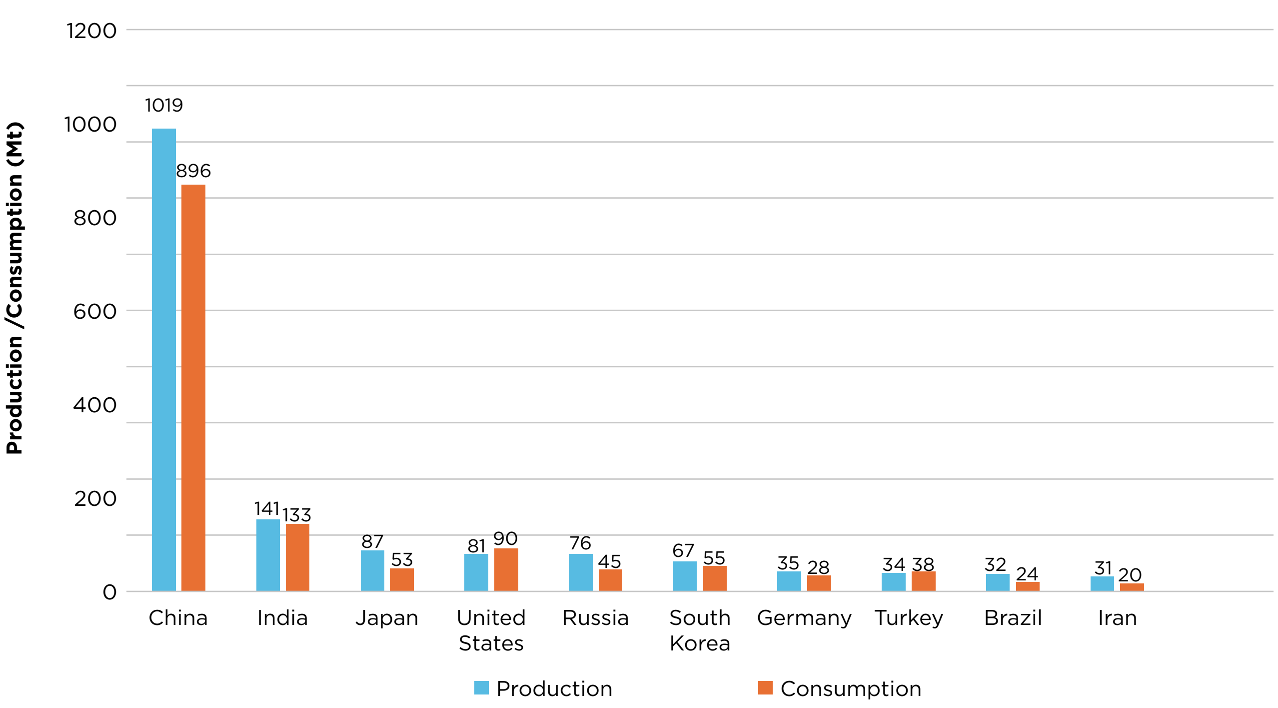


Figure 2.5: Global comparison of steel production and consumption (million tonnes)

Source: *(World Steel, 2024) (WEF, 2022) (Hasanbeigi, 2022), For India, Source: (MoS, 2025)*

Steel Sector in India

India is the world's second-largest crude steel producer, with output rising to 152.18 Mt in FY 2024–25 (Ministry of Steel; WSA, 2025). Under the National Steel Policy (NSP) 2017, India targets a steelmaking capacity of 300 Mt and production of 255 Mt by FY 2030–31, underscoring the sector's central role in supporting economic growth.

Finished steel consumption has grown strongly, expanding at a CAGR of 7.6% from around 31 Mt in 2002–03 to about 152 Mt in 2024–25, driven by rapid urbanisation and infrastructure development. Despite this growth, per capita finished steel consumption in India remains modest at about 98 kg in 2023–24 (rising to 102.6 kg in 2024–25), less than half the global average of around 215–220 kg, indicating substantial headroom for future demand as incomes and investment increase. Steel demand is concentrated in construction (43%) and infrastructure (25%), followed by engineering and packaging (22%), automobiles (9%), and defence (1%).

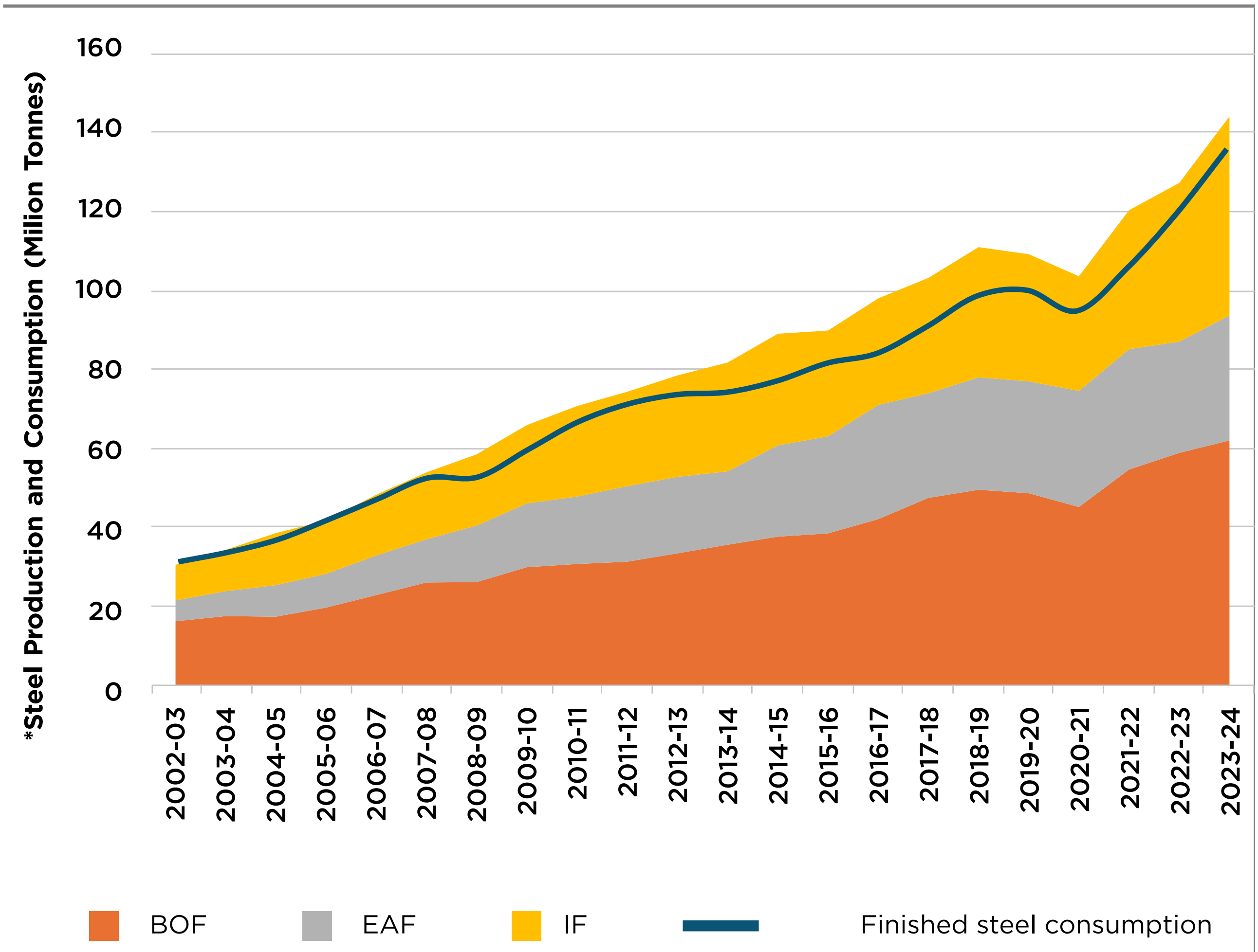


Figure 2.6: Historical production and consumption of steel (million tonnes) (MoS, 2024)

*Steel production route/processes:
BOF: Basic Oxygen Furnace,
EAF: Electric Arc Furnace
IF: Induction Furnace

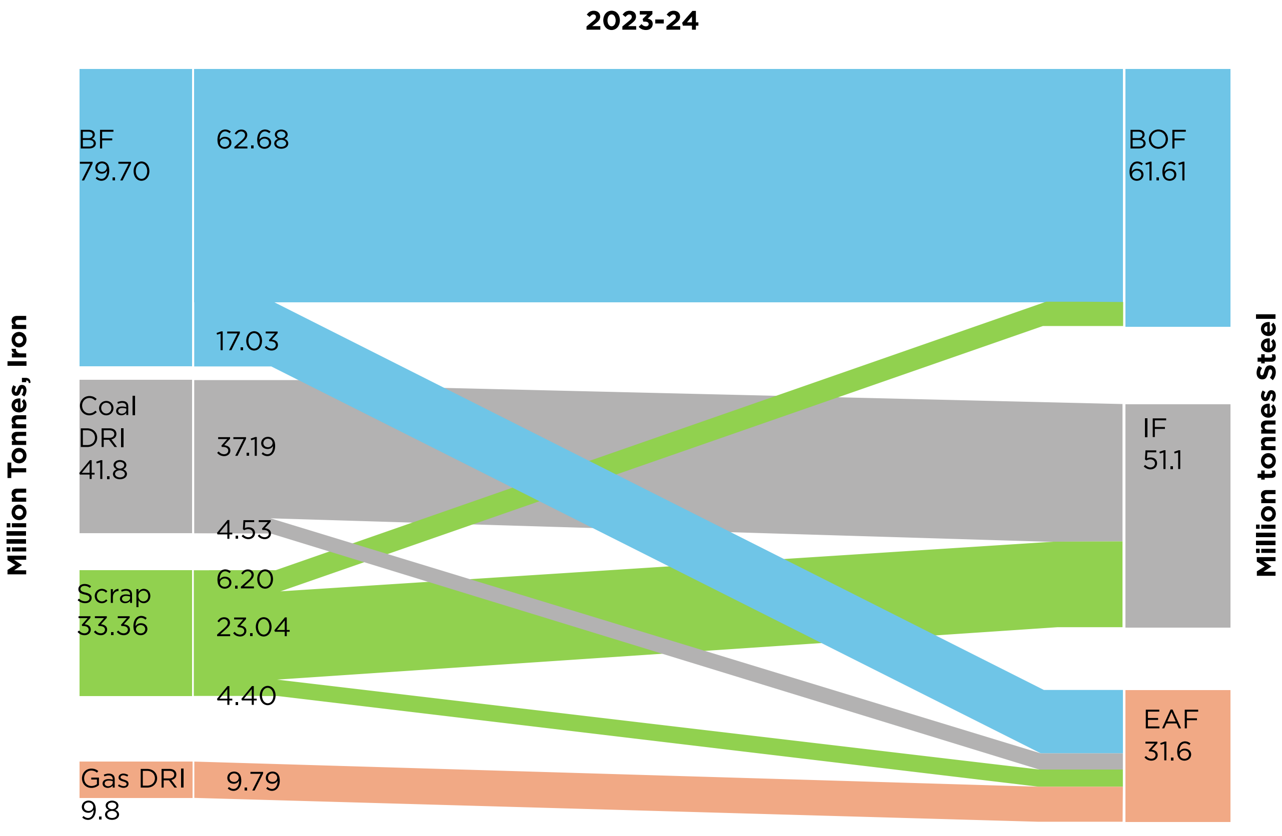


Figure 2.7: Technology-wise steel production, 2023-24 (MoS, 2024)

Indian steel production relies on a mix of technologies. The primary routes are: Blast Furnace–Basic Oxygen Furnace (BF-BOF; the dominant route), Direct-Reduced Iron (DRI) with Electric Arc Furnace (DRI–EAF; using gas or coal-based reduction), and DRI with Induction Furnace (DRI–IF; coal-based) (Figure 2.7). A significant contribution of crude steel is from coal based DRI which is responsible for India's higher steel sector emission intensity of approximately 2.54 tonnes CO_2 per tonne of crude steel (tCO_2/tCS), compared to the global average of 1.9 tCO_2/tCS in FY 2023-24 (IEEFA & JMK Research 2023).

This diverse mix spans from large integrated plants to small secondary steel mills. These technology choices also shape energy consumption. For example, the BF-BOF route, which dominates India's steel production, averages 27.3 GJ/tonne, substantially higher than global best practice (20–22 GJ/t). Conversely, scrap-based EAF steel is significantly more efficient at just 1.4 GJ/t, reflecting alignment with circular economy principles but constrained by scrap availability (21% share of total production in 2024) (Ministry of Steel, 2024). These contrasts are evident in the technology/fuel-wise Specific Energy Consumption (SEC) (see Figure 2.8).

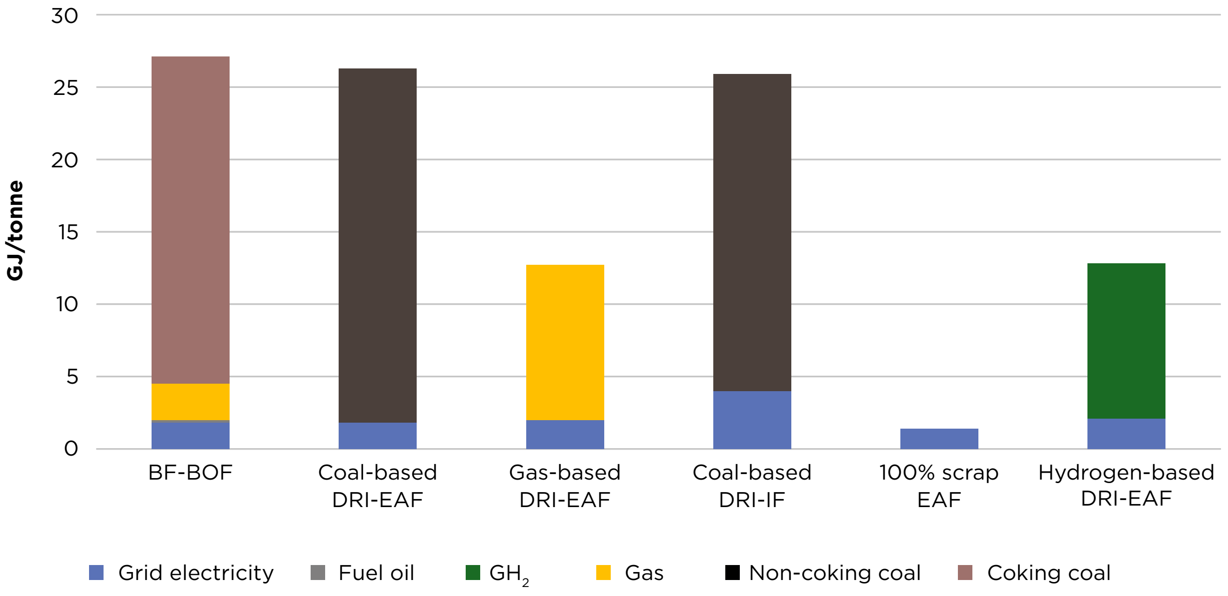


Figure 2.8: Estimated fuel-wise specific energy consumption[1]

The total energy consumed in 2020 and 2025 is 48 Mtoe and 68.8 Mtoe, respectively, accounting for electricity generation from captive power plants rather than associated fuel consumption. The detailed fuel mix for 2020 is given in Figure 2.9.

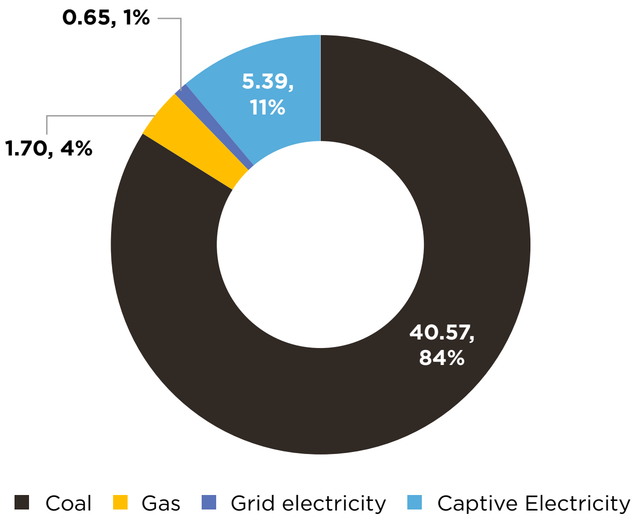


Figure 2.9: Energy mix (Mtoe, %) in steel sector in 2020

To address the steel sector's low-carbon transition challenges, India is exploring green Hydrogen as a low-emission pathway for steel. Steelmaking is a global priority for green hydrogen deployment, with over 200 hydrogen-based projects announced by 2030 (Clean Energy Ministerial, 2024). India's National Green Hydrogen Mission targets 5 Mt of annual green hydrogen production by 2030 (MNRE 2024), with INR 455 crore allocated to pilot hydrogen-based steelmaking projects (PIB, 2024).

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[1] Estimated based on the mix of grid electricity and fuel required for the thermal energy and captive electricity for different technology type.

Key Policies and Initiatives for the Steel Sector

Global Policies	Indian Policies
Global steel policy is increasingly shaped by carbon pricing, clean tech funding, and material efficiency or circular economy mandates. The EU ETS applies carbon pricing to steel producers, while CBAM imposes tariffs on imported high-emission steel (ICAP, 2024). In the United States, the Inflation Reduction Act (IRA) allocates substantial funding to support clean technology initiatives within the steel industry, promoting the adoption of low-carbon production methods (Phadnis, 2024). Korea steel decarbonisation policies focus on broad aspects of steel sector decarbonisation, including advancing low-carbon technologies such as Hydrogen-reduction, CCS, EAF and Steel Scrap; developing high-value added materials; enhancing export competitiveness (InfluenceMap, 2025). The Clean Steel Partnership, officially launched in June 2021, seeks to advance various breakthrough technologies to produce clean steel on a large scale by 2030 (EU, 2022). Collectively, these policies aim to enhance sustainability in the global steel sector. Initiatives like the World Steel Association's roadmap and global buyer-led initiatives such as the First Movers Coalition are reinforcing demand for green steel.	The National Steel Policy (NSP), 2017 envisions a globally competitive and self-reliant steel industry. It targets per capita consumption of 160 kg by 2030–31, aims to meet domestic demand for high-grade automotive, electrical, and special steels, and seeks to reduce coking coal import dependence from ~85% to ~65%. The policy further emphasizes expanding global presence in value-added steel, promoting energy-efficient and environmentally sustainable production, ensuring cost-effective and quality manufacturing, and achieving global standards in safety, health, and carbon footprint reduction. The Steel Research Technology Mission of India (SRTMI) is a joint initiative of the Indian steel industry and academia supported by the Ministry of Steel, to drive innovation and research in the steel sector and bridge gaps between industry and academia for enhanced R&D. A Green Steel Taxonomy was introduced with 3-star, 4-star, and 5-star ratings based on CO_2 intensity (MoS, 2024). Certifications like LEED (Leadership in Energy and Environmental Design) and GRIHA (Green Rating for Integrated Habitat Assessment) encourage the use of energy-efficient, low-emission steel in infrastructure and real estate projects. The Steel Scrap Recycling Policy (2019) and Vehicle Scrappage Policy (2022) aim to enhance scrap availability (IEA, 2024).

Global Policies	Indian Policies
⏩ Countries such as China, Germany, India, Japan, and Korea have created policies on circular economy and material efficiency to boost scrap availability (OECD, 2024).	⏩ Under the National Green Hydrogen Mission, a budgetary support of ₹455 crore has been allocated to the Ministry of Steel for implementation of pilot projects for the use of hydrogen in the iron and steel sector up to the financial year 2029–30 (NGHM, MNRE). Under the Mission, Ministry of Steel has awarded pilot projects in key focus areas i.e., use of hydrogen in existing Blast Furnace to reduce coal/coke consumption; and injection of hydrogen in vertical shaft based DRI making to partially substitute the NG/other reducing gas Greening the Steel Sector in India: Roadmap & Action Plan is key policy framework issued by Ministry of Steel (MoS) to guide sector's transition towards low-carbon intensity, including energy efficiency, use of renewable energy and green hydrogen, material efficiency, technology shift from coal-based DRI to cleaner route and CCUS.

Box-1: HYBRIT – Sweden's Shift Towards Fossil-Free Steel with Hydrogen[1,2]

Green hydrogen is emerging as a key option for reducing emissions in the steel industry. Sweden is one of the first countries to take large-scale action through the HYBRIT (Hydrogen Breakthrough Ironmaking Technology) initiative. Under this initiative, three major companies, SSAB, LKAB, and Vattenfall, are working together to change the Swedish iron and steel industry by replacing coal with fossil-free hydrogen in the steelmaking process. As part of this effort, they are also developing large-scale storage systems for fossil-free hydrogen gas. The HYBRIT initiative has already produced trial batches of fossil-free steel and is seen as among the earliest realistic steps towards commercial hydrogen-based steel production.

India is exploring similar solutions. While the steel sector in India still relies on blast furnaces, some pilot projects for hydrogen-based steelmaking have started. For example, Tata Steel has conducted a trial to inject hydrogen into its blast furnace as a partial replacement for coal. This marks an early step in India's move toward low-carbon steel using green hydrogen.

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[1] https://www.hybritdevelopment.se/en/

[2] Tata Steel Press Release

Box-2: Clean Steel Partnership (ESTEP 2024)

The Clean Steel Partnership (CSP) was launched in 2021 to help achieve the EU's climate neutrality target by 2050. Its main objective is to cut CO_2 emissions from steel production by 80–95%, with a 50% reduction by 2030. The CSP operates under the European Green Deal through a public-private partnership. Funding comes from public sources like Horizon Europe and private industry contributions, aiming to mobilize Euro 2.6 billion (INR 23,400 crore), including Euro 1 billion (INR 9,000 crore) from public funds. It focuses on advancing clean steel technologies, including hydrogen-based steelmaking, Carbon Direct Avoidance (CDA), and Carbon Capture and Usage (CCU), to Technology Readiness Level (TRL) 8. The funding supports demonstration projects and deployment. Over 100 stakeholders are involved, including EUROFER, ESTEP, and leading European steelmakers.

Box-3: Carbon Border Adjustment Mechanism (CBAM) (European Union, 2023)

The European Union's Carbon Border Adjustment Mechanism (CBAM), introduced on October 1, 2023, imposes levies on imports of carbon-intensive goods such as steel, aluminium, and fertilisers based on their embedded CO_2 emissions. This mechanism aims to prevent 'carbon leakage' by ensuring that imported products are subject to the same carbon costs as those produced within the EU.

Key Features:

- *Transitional Phase (2023–2025):* Importers must report the embedded emissions of covered goods without financial obligations.
- *Full Implementation (from 2026):* Importers will be required to purchase CBAM certificates corresponding to the carbon price that would have been paid if the goods were produced under the EU's Emissions Trading System.

Implications for India (CSEP 2025):

- *Trade Impact:* As a significant exporter of steel and aluminium to the EU, Indian steel's cost may increase, potentially affecting its competitiveness.
- *Compliance Challenges:* Indian exporters will need to develop robust mechanisms for measuring and reporting the carbon content of their products to comply with CBAM requirements.
- *Strategic Considerations:* India may need to enhance its domestic carbon pricing mechanisms and invest in low-carbon technologies to maintain market access and competitiveness in the EU.

CBAM represents a significant shift in global trade dynamics, linking carbon emissions directly to trade policies. For India, proactive engagement and policy adjustments will be crucial to navigate the consequent challenges and opportunities.

2.2.2 Cement Sector

Global Context

The cement industry accounts for 13% of global GDP and 8% of global emissions (GCCA & TERI, 2025). With 68% of the global population projected to live in urban areas by 2050, cement demand will be driven by South and Southeast Asia, Africa, the Middle East, and Latin America (UN DESA, 2018). China currently produces about half of the world's cement, followed by India (see Figure 2.10). India's per capita cement consumption is approximately 257 kg, less than half the global average of about 540 kg (GCCA and TERI, 2025), indicating significant growth potential.

Globally, the cement sector was the third-largest industrial energy consumer in 2022, using 12 Exa Joules (3,333 TWh) or 7.18% of industrial energy (IEEFA & JMK Research, 2023). Around 50-60% cement production emissions are generated from limestone during the calcination process, 30-40% are from fossil fuel combustion, and the remaining approximately 10% from electricity use in grinding, material handling, and plant operations. Indian cement plants are relatively energy-efficient due to early adoption of technologies such as high-efficiency kilns, waste heat recovery systems, and clinker substitution using supplementary cementitious materials (SCMs) like fly ash and slag (CEEW, 2023).

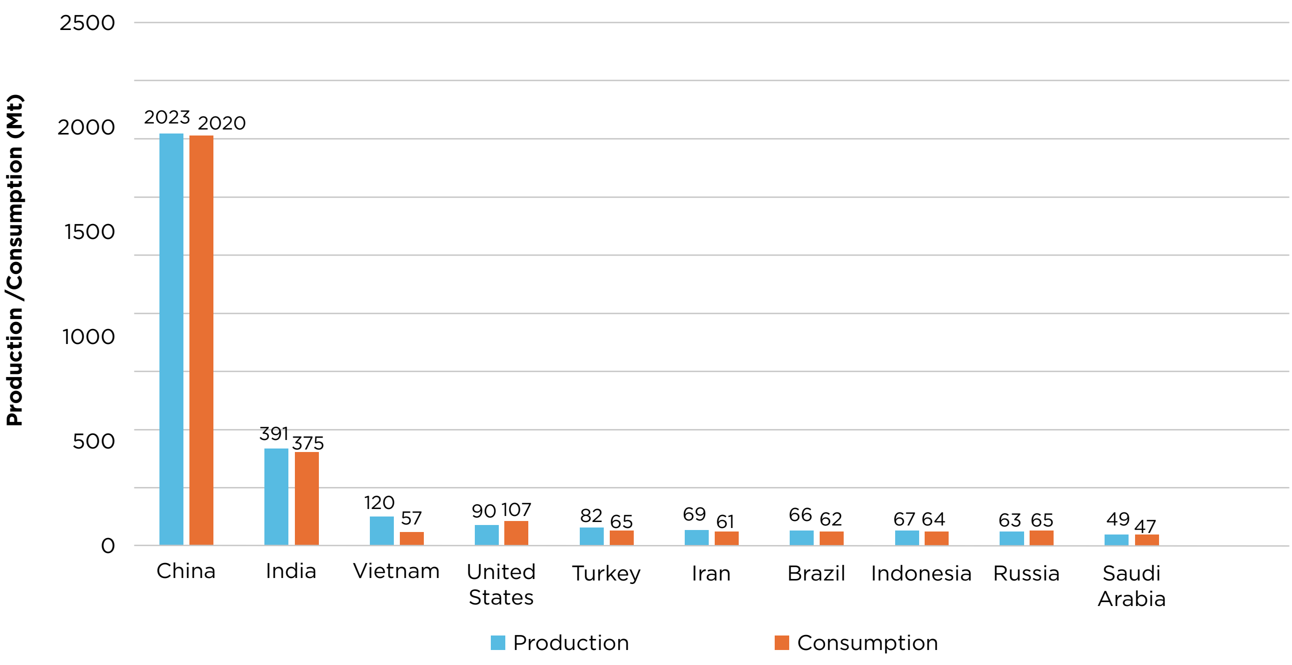


Figure 2.10: Global comparison of cement production, consumption, emissions, and per capita consumption (million tonnes)

Source: *(Worldpopulationreview, 2023) (USGS, Cement - United States Geological Survey 2023, 2023) (USGS, Cement - United States Geological Survey 2023, 2023) (EUCementAssociation, 2023), For India, Source: (India Climate & Energy Dashboard)*

Cement Sector in India

India is the world's second-largest cement producer, accounting for over 8% of global installed capacity and annual output reaching 453 million tonnes in FY25, largely under private ownership, reflecting a mature, competitive industry (IBEF, 2025). Cement and its products contributed to 0.88% of India's GDP in 2023-24 (MoSPI, 2025; RBI, 2025). The sector is the fifth-largest contributor to the Indian economy and supports infrastructure, employment, and socio-economic growth. It provides one million direct jobs and supports another 20,000 downstream jobs per million tonnes of cement produced and consumed (CMA, 2022). Rapid urbanisation and government-led infrastructure initiatives such as PM Awas Yojana–Gramin (PMAY-G), PM Gati Shakti, and Smart Cities are driving cement demand. As shown in Figure 2.11, from FY 2019 to 2024, domestic demand grew at about 6% CAGR, recovering strongly after the COVID-19 pandemic with 8% growth in FY 2022 and about 9% in FY 2023 (MOSPI, 2025). By FY 2024, infrastructure became the key growth driver, and the momentum is expected to continue through initiatives like Ude Desh ka Aam Naagrik (UDAN) scheme for regional airport expansion, and ongoing National Highway and Bharatmala road development projects (Ministry of Finance, 2025).

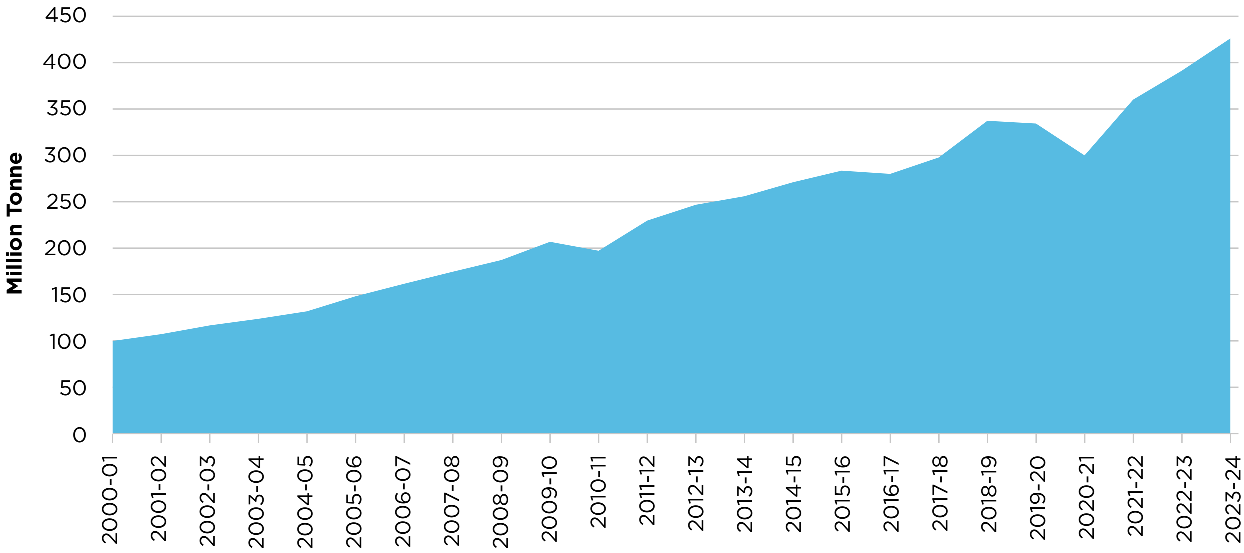


Figure 2.11: Historical production of cement (million tonnes)

On the technology and product mix, nearly 99% of India's cement is produced using the dry process with preheater–precalciner kilns, which is significantly more energy efficient than older wet processes. Blended cements dominate production, with Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) accounting for about 72% of total output (of which PPC alone accounts for 65%), while Ordinary Portland Cement (OPC) constitutes around 27%. Emerging low-clinker cements such as Limestone Calcined Clay Cement (LC3) and Portland Limestone Cement (PLC) are gradually entering the market (Cement Manufacturers Association). The extensive use of supplementary cementitious materials (such as fly ash and slag, etc.) have reduced the clinker-to-cement ratio to 0.67 by 2024, better than the global average (0.76), thereby lowering the sector's carbon intensity (WRI, 2024).

The cement industry is both energy-intensive and process-intensive, and was responsible for emissions of approximately 179 $MtCO_2e$ in 2019 (MoEFCC, 2023) and 296 $MtCO_2e$ in 2025 (estimated).

The cement sector consumes around 690-710 kcal/kg (~3.1 GJ/t) of thermal energy and 50 kWh/tonne of electricity for clinker production and 70-80 kWh/tonne of electricity for final cement production. Operating among the most energy-efficient cement industries globally, the sector reflects widespread adoption of modern kilns, waste-heat recovery systems, and efficient operational practices (Confederation of Indian Industry, 2025). The overall energy consumption, accounting for electricity generation from captive power plants rather than associated fuel consumption, remains at 18 and 27 Mtoe in 2020 and 2025, respectively, with electricity contributing about 12% of the energy demand (see Figure 2.12).

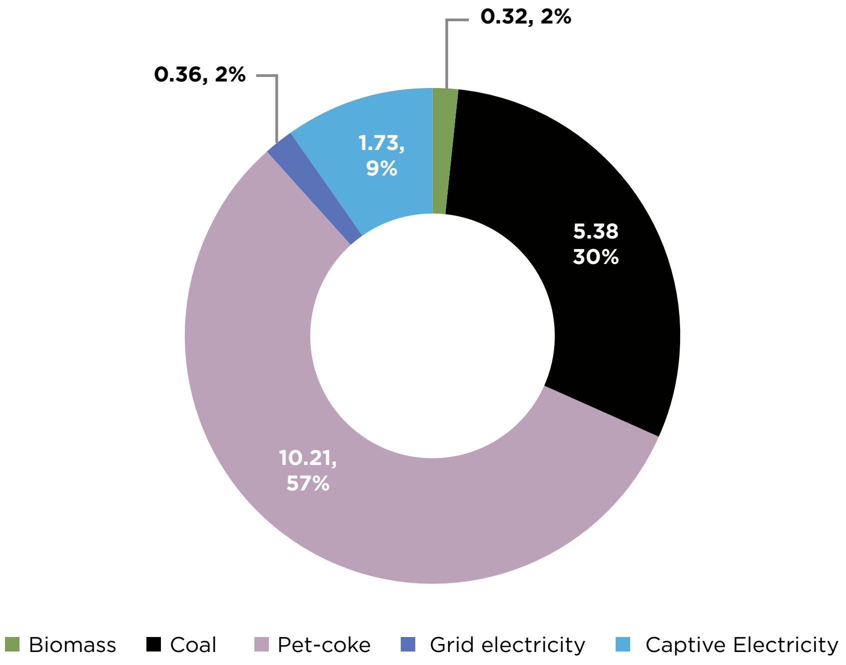


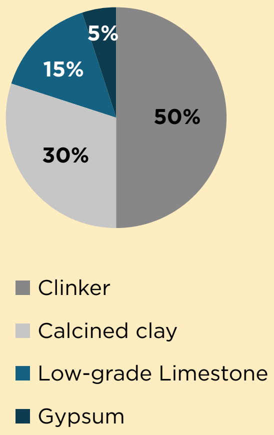
Figure 2.12: Energy mix (Mtoe, %) in cement sector in 2020

While India's cement sector is among the most energy-efficient globally, the dominance of coal and pet coke persists with limited use of alternative fuels (mainly from biomass, industrial wastes, and Refuse-Derived Fuel (RDF)).

India is also advancing low-carbon cement alternatives. Blended cements such as Portland Composite Cement (PCC), Portland Limestone Cement (PLC), Portland Dolomitic Limestone Cement (PDC), Limestone Calcined Clay Cement (LC3), and other multicomponent blends are in various development stages (GCCA & TERI 2025). Emerging options like Geopolymer and Super Sulphated Cement require further research and standards. LC3, in particular, is gaining traction domestically and internationally, and a BIS standard (IS 18189:2023) was introduced in June 2023 to support its uptake. Its commercial production plants in Europe are expected to commence by 2025 (RMI, 2023). Major cement producers have also invested significantly in renewables and waste heat recovery, adding about 600 MW of renewable capacity in the past decade. India is also taking early steps toward integrating carbon capture, utilisation, and storage (CCUS) in cement production as part of its long-term low-carbon transition strategies (JSW Cement 2024).

Box-4: Limestone Calcined Clay Cement (LC3) is a promising low carbon substitute both in terms of raw material availability and process maturity

Typical Composition of LC3[2]



Around 50-60% of emissions in the cement industry come from clinker production. To reduce this, it is important to bring down the clinker content in cement. Limestone Calcined Clay Cement (LC3) cement does exactly that, it brings the clinker ratio down to about 50%, compared to OPC which typically has clinker content of around 90-95%. LC3 technology has been scaled up in parts of Africa and South America, mainly to reduce clinker imports. India could benefit from such initiatives as it works to reduce its emissions. India has enough raw material to support this shift. As of 2015, clay and limestone reserves stood at 9,294 million tonnes and 16,000 million tonnes respectively (LC3 EPFL, 2024; TERI).

Key Policies and Initiatives for the Cement Sector

As a developing country and among the fastest-growing economies, India has robust cement demand and long-term potential from infrastructure development (GCCA India & TERI, 2025). Low-carbon transition policies for the cement sector include clinker substitution, blended cement, alternative fuels, material and energy efficiency measures, and CCUS. The decarbonisation of other sectors—power and buildings—also has a major impact on cement sector decarbonisation (GCCA India & TERI, 2025). Policies promoting low-carbon cement like LC3 reflect India's commitment to decarbonise the sector.

Global Policies	Indian Policies
Global cement policy is increasingly shaped by carbon pricing, product standards, and carbon capture mandates. The EU Emissions Trading System (EU ETS) applies carbon pricing to cement producers, while the EU's Carbon Border Adjustment Mechanism (CBAM) covers cement imports from 2026, discouraging high-emission production (ICAP, 2024; EC, 2023).	The Greenhouse Gas Emission Intensity Target Rules (2025) impose India's first legally binding CO_2 intensity targets on cement plants, requiring reductions per tonne of output under the Carbon Credit Trading Scheme (MoP, 2025). The BIS standard IS 18189:2023 supports LC3 cement, enabling about 30% emissions reduction (BIS, 2023).

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[2] TARA: Environmental and Resource Assessment for Uptake of LC3 in India's Cement Mix

Global Policies	Indian Policies
Ireland mandates 30% clinker substitution in all publicly funded projects (Kumar, 2025). The US Buy Clean Initiative (2021) mandates low-carbon cement use in federal projects (Kumar, 2025). China's government launched a Carbon Peak Implementation Plan for Building Materials (2022) to ensure cement sector emissions peak before 2030 through low-carbon technologies, energy efficiency, and cleaner energy use. In GCCA 2050 roadmap to Net Zero, leading companies from Global Cement and Concrete Association have joined forces to set a collective goal of achieving carbon-neutral concrete production by 2050. The ASEAN Federation of Cement Manufacturers'(AFCM) plan is the world's first regional strategy for cement to guide the Southeast Asian cement sector in reducing CO_2 emissions through expanding low-carbon cement, use of renewable energy, energy efficiency and deploying CCUS.	The Fly Ash Utilisation Notification mandates the use of fly ash from thermal power plants, strengthening clinker substitution and circular material use in cement production (MoEFCC, 2021). Waste Management Rules legally enable co-processing of municipal, hazardous, and plastic waste in cement kilns, supporting fuel substitution and emissions reduction (MoEFCC, 2016–2022). India's National Taskforce on Alternative Fuels and Raw Materials (AFR) aims to facilitate greater adoption of waste-derived materials (plastic, tyres and biomass residues) as fuel and substitute for coal/limestone in energy-intensive cement sector (Institute of Industrial Productivity).

2.2.3 Aluminium sector

Global Context

Aluminium's light weight, corrosion resistance, and recyclability make it integral to modern industry, particularly in transport, construction, and electrification. Global aluminium production increased from 45.9 million tonnes in 2006 to 70.7 million tonnes in 2023 (USGS, 2010; IAI 2024). China remains the dominant player and produced around 42 million tonnes in 2023 (59% of global output), followed by India, which reached a record capacity of 4.1 million tonnes in 2022–23 (BEE, 2024; SMM China, 2025).

Aluminium is a major economic contributor. Globally, it generates USD 73 billion in direct output and supports 7.5 million jobs (Energy Transition Commission, 2022). In India, though consumption remains low, aluminium contributes to 2% of manufacturing GDP and supports nearly 800,000 jobs (NITI Aayog). However, its expansion poses significant environmental challenges. The sector emits approximately 1.1 billion tonnes of CO_2 annually, nearly 2% of global emissions and is projected to rise by 50% by 2050 under business-as-usual scenarios (Energy Transition Commission, 2022).

As global industries commit to Net Zero targets, the share of recycled aluminium is expected to rise to 45% by 2030 (WEF, 2023). Leading OEMs aim to use 40–80% recycled aluminium, driving investments in secondary production and scrap supply chains (FICCI, 2024; Energy Transition Commission 2023).

Primary producers are also investing in low-carbon aluminium (under 4 tCO_2e/t), prioritising non-fossil electricity, energy efficiency, and carbon capture technologies. Since 60% of emissions are generated by electricity use, reducing emissions from power supply through solar, wind, and increasingly, nuclear power is critical. Small Modular Reactors (SMRs), under development globally, offer promise as a steady, low-carbon power source for energy-intensive industries.

Box-5: Aluminium Dunkerque (France) – Leveraging Nuclear Power for Low-Carbon Aluminium[3]

Located in France, Aluminium Dunkerque leverages a nuclear-powered grid to significantly reduce its emissions. This model demonstrates how stable, low-carbon electricity can enable low-emissions aluminium production.

India's aluminium producers have adopted prebaked anode technology, replacing older Söderberg methods to improve efficiency and reduce emissions. Emerging technologies such as inert anodes, carbochlorination, and carbon capture and storage (CCS) are being explored to further reduce emissions to as low as 0.2 tCO_2/t.

In parallel, there is a growing focus on Scope 3 emissions[4] across the aluminium value chain. Automakers and construction firms are aligning with global targets to cut emissions by 25–100% by 2030 reinforcing the need for cleaner supply chains and circular material flows.

Aluminium Sector in India

India is the world's second-largest producer of primary aluminium, with an output of approximately 4.2 million tonnes in 2024. However, domestic consumption at 3-4 kg per capita per year is lower than the global average of 11-13 kg and China's consumption of over 25-30 kg (Ministry of Mines, 2025). Demand is expected to grow rapidly due to expansion in infrastructure, power, transport, packaging and manufacturing activities. The aluminium industry contributes to roughly 2% of India's manufacturing GDP and supports nearly 0.8 million direct and indirect jobs (Kumar, 2025). India's aluminium market is dominated by primary production (70–75%). Secondary (recycled) aluminium is only 25–30% of total output (Figure 2.13), lower than the global average of 40%. Due to low domestic scrap availability, 85-90% of scrap used in India is imported (Ministry of Mines, 2025).

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[3] Pioneering Sustainable Aluminium: Aluminium Dunkerque's Decarbonisation and Partnership Strategy

[4] Scope 3 emissions are the indirect GHG emissions that come from a company's supplier value chain

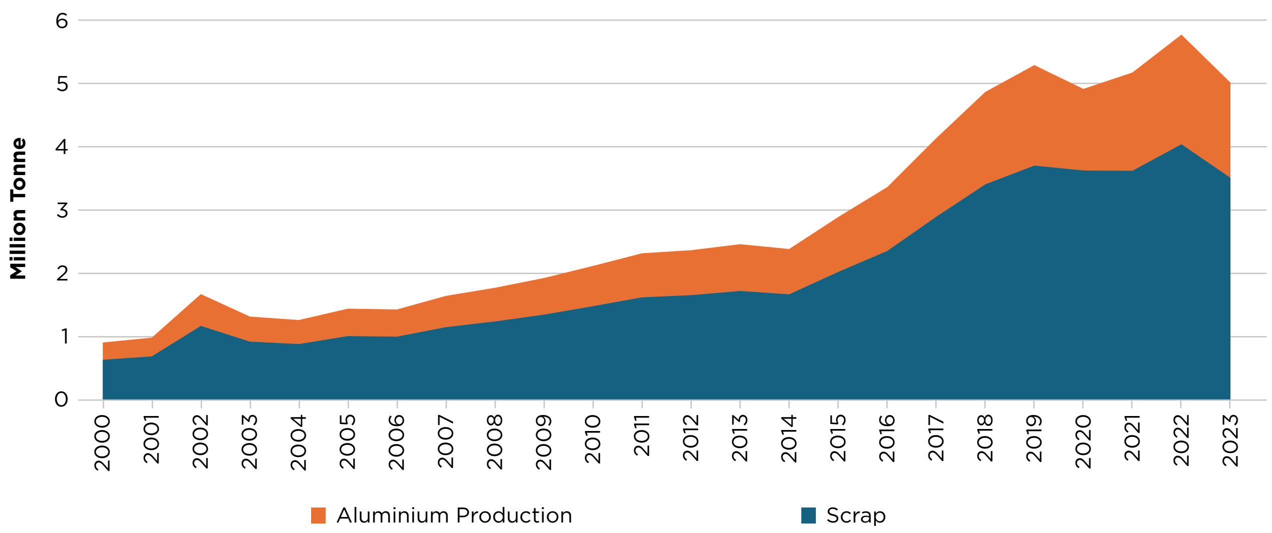

Figure 2.13: Historical production of aluminium (million tonnes)

Aluminium production is one of the most energy-intensive processes. Indian primary smelters consume an average of 20-28 GJ/t of thermal energy (mainly for alumina refining and anode baking), and 50-51 GJ/t of electricity (for aluminium smelting), totalling around 70-80 GJ/t (≈ 1.68 toe/t), higher than the global best practice of 63–65 GJ/t (Sripathy, et.al., 2024). In contrast, secondary aluminium production requires only 10-10.8 GJ/t (2.8-3 kWh/t), roughly 15% of the energy of primary smelting, underscoring the critical role of recycling in low-carbon transition (Raabe et. Al, 2022). The sector's total final energy consumption was around 6.4 Mtoe in 2020 (Figure 2.14), including both thermal energy and electricity. When fuel consumption for captive electricity generation is included, the total energy use amounts to 14.38 Mtoe in 2020. The fuel mix is coal-dominated, with minimal use of RE integration in electricity generation so far.

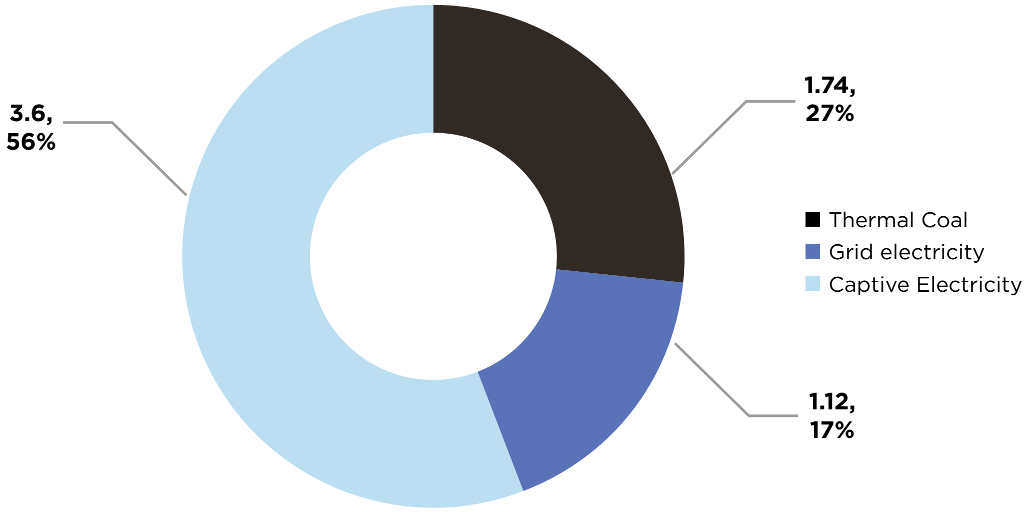

Figure 2.14: Energy mix (Mtoe, %) in aluminium sector in 2020

This is because aluminium smelting requires continuous, high-reliability power, leading to long-term reliance on captive coal-based generation amid limited availability of firm renewable alternatives. Sectoral emissions are projected to be about 135 $MtCO_2e$ in 2025 (around 3.3% of India's total GHG emissions). Emission intensity is estimated at 23.5 tCO_2 per tonne, well above the global average of 16 tCO_2/t. Around 57% of these emissions arise from energy use, predominantly captive coal power, while the remainder comes from process emissions associated with carbon anode consumption and Perfluorocarbons (PFCs) releases (CF_4, C_2F_6). India's aluminium sector exhibits comparatively high CO_2 intensity, making it a strong candidate for rapid decarbonisation through clean power procurement, expanded recycling, and the deployment of inert anode and CCUS technologies, in alignment with India's long-term Net Zero objectives.

Key Policies and Initiatives for the Aluminium Sector

The aluminium industry is highly energy-intensive, consuming an average of 14,361 kWh of electricity per tonne of aluminium produced. Recognising the environmental and energy challenges associated with producing primary aluminium, India has introduced measures to enhance scrap recycling to produce secondary aluminium, which uses just 5% of the energy used in primary aluminium production. In addition, the PAT scheme has driven significant energy efficiency improvements in the aluminium industry, achieving cumulative energy savings of 2.13 million tonnes of oil equivalent (Mtoe) (BUR 4 Report 2024).

Global Policies	**Indian Policies**
⏩ The EU's Carbon Border Adjustment Mechanism will apply to aluminium from 2026, levying carbon costs on imported aluminium. ⏩ China included Aluminium in its national Emissions Trading System in 2024 (as the source of ~60% of global aluminium) (IEA) ⏩ Major producers are piloting breakthrough technologies – e.g. inert anode smelting (Canada's Elysis project) and electrified alumina refining – alongside carbon capture to achieve near-zero-emission primary aluminium.	⏩ The Non-Ferrous Metal Scrap Recycling Framework promotes circularity and secondary production (PIB, 2025). ⏩ The Greenhouse Gas Emission Intensity Target Rules (2025) impose legally binding CO_2 intensity reduction targets on aluminium producers from 2025, requiring a 2.8%-7.1% reduction in CO_2 per tonne under CCTS (MoP, 2025). ⏩ Electricity regulations, including open access provisions and Renewable Purchase Obligations (RPOs), increasingly affect aluminium smelters, given their high dependence on power and indirect emissions (MoP; SERCs).

2.2.4 Fertiliser sector

Global Context

The fertiliser industry plays a pivotal role in enhancing agricultural productivity, contributing significantly to global food security and economic growth. In 2023–24, global fertiliser production stood at approximately 218 million tonnes. Within fertilisers, urea production reached approximately 184 million tonnes out of 218 million tonnes of total fertilisers globally, with China and India contributing around 40% of global urea output. The global fertiliser market, valued at USD 145 billion in 2023, has grown at a modest 1% annually over the past decade. In contrast, India's market, valued at USD 11.32 billion, is projected to grow at a CAGR of 4.2%, reaching USD 16.58 billion by 2032, driven by rising demand and government subsidies (IBEF, 2024).

Globally, the fertiliser industry contributes to around 1.3% of total CO_2 emissions, and ammonia production alone consumes 2% of global energy. Enabling low-carbon strategies for the sector centres on three key pathways: energy efficiency, fuel switching, and green ammonia. Energy efficiency improvements in urea production can reduce thermal energy demand by up to 10%. Transitioning to round-the-clock renewable energy (RTC RE) can reduce dependence on coal- and gas-based captive power. The most promising long-term solution is the adoption of green ammonia, which addresses nearly 80% of emissions from fertiliser manufacturing (CEEW 2024).

Despite technological improvements, fertiliser production remains highly energy- and emission-intensive. Ammonia production is the dominant source, accounting for 90% of the sector's energy use. The shift from coal to natural gas as the primary feedstock has improved efficiency; coal usage fell from 2.13 million tonnes in 2016–17 to 0.80 million tonnes in 2023–24. The fertiliser sector accounts for 31% of India's total natural gas consumption, driven by urea production, which increased from 15,429 MMSCM in 2016–17 to 19,400 MMSCM in 2022–23 (BEE, 2024).

Box-6: Scheme Guidelines for implementation of SIGHT Programme

Component II: Incentive for Procurement of Green Ammonia Production (under Mode2A) of the National Green Hydrogen Mission (NGHM). Mode 2A caters to the requirements of the fertiliser sector. As per the said Guidelines, the capacity available for bidding under Tranche I of Mode 2A was 5,50,000 tonnes per annum of Green Ammonia. Thereafter, Solar Energy Corporation of India (SECI) also issued Request for Selection (RfS) for selection of Green Ammonia Producers through a cost based competitive bidding process (Ministry of New and Renewable Energy, 2024).

Fertiliser Sector in India

India ranks as the second-largest consumer and third-largest producer for fertilisers, accounting for about 20% of global output (CEEW, 2024). In 2023–24, India consumed 60 million tonnes of fertilisers, including 35.78 million tonnes of urea, 10.97 million tonnes of DAP, 1.64 million tonnes of MOP, and 11.68 million tonnes of NP/NPK fertilisers. Nutrient use intensity reached 141.2 kg/ha in 2022–23, with 13 states led by Uttar Pradesh, Maharashtra, and Madhya Pradesh accounting for 92% of total consumption (FAI 2024). Globally, South Asia and Latin America are expected to drive fertiliser demand growth through 2027, influenced by climate stress, changing rainfall patterns, and evolving farming practices (IFASTAT, 2023). By 2023-24, India's total fertiliser production reached about 50 million tonnes (Department of Fertiliser, 2025). In 2023-24, India imported 17.69 million tonnes of fertilisers, comprising 7.04 million tonnes of urea, 5.56 million tonnes of DAP, 2.21 million tonnes of NP/NPK, and 2.86 million tonnes of Muriate of Potash (MOP) (Department of Fertiliser, 2025).

Figure 2.15 shows the historical production trend of major fertiliser production in India[5]. Urea remains the leading product. Despite its significant production capacity, India remains heavily import-dependent, particularly for Di-Ammonium Phosphate (DAP), Complex Fertilisers (CFs) and even urea - due to limited access to key raw materials such as phosphate rock and ammonia.

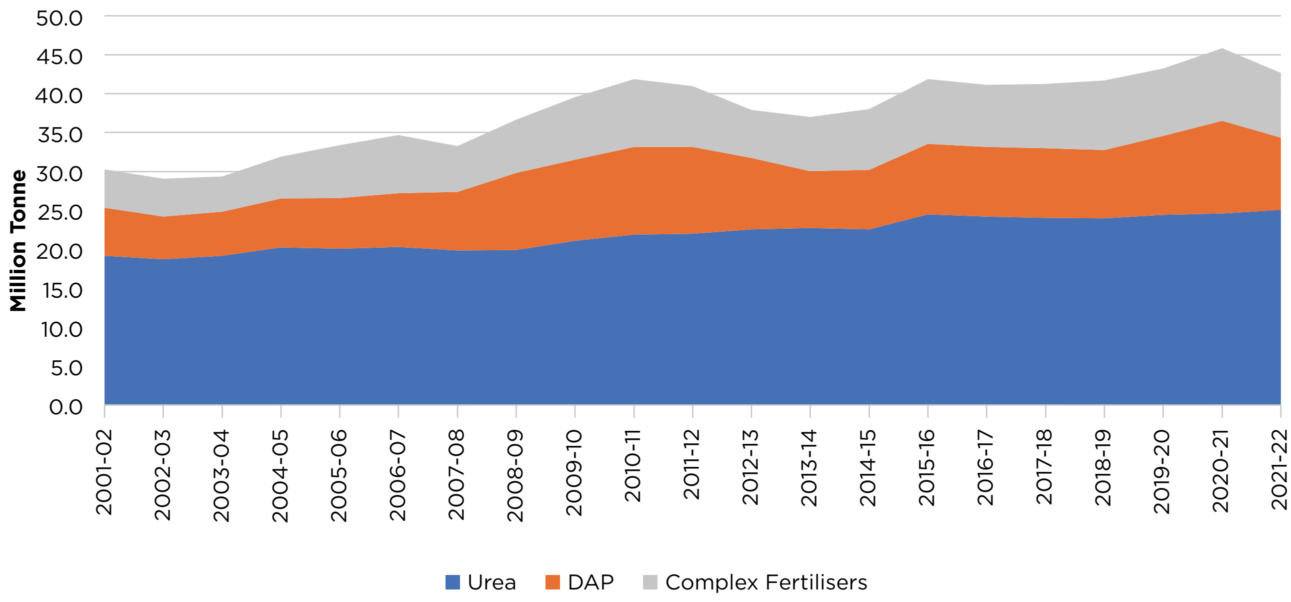

Figure 2.15: Historical production of major fertilisers, (million tonnes)

India's fertiliser industry is highly emissions-intensive, primarily due to its reliance on grey hydrogen produced through steam methane reforming of natural gas during ammonia production. Urea, the most commonly produced fertiliser, requires approximately 0.575 tonnes of ammonia per tonne produced. DAP and other complex fertilisers consume ammonia to a lesser extent, at a lower extent of 0.23 tonnes per tonne produced (Baboo, 2015). Ammonia production and its conversion into fertilisers contribute substantially to GHG emissions, totalling around 25 million tonnes of CO_2 in 2022–23, 65% of which is attributed to urea alone (Patidar et. al, 2024). Natural gas is used as both a feedstock and a thermal energy source. Given its significant emissions footprint, the fertiliser sector is a key focus for India's industrial low-carbon transition effort.

Figure 2.16 provides the information on the specific energy consumed in different types of fertilisers. Energy efficiency has gradually improved, as the average Specific Energy Consumption (SEC) for urea production has reduced to 17.88 GJ/tonne (treating hydrogen as fuel and accounting for electricity generation from captive power plants rather than associated fuel consumption).

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[5] This output is primarily driven by urea, di-ammonium phosphate (DAP) and other complex fertilisers (OCFs), which together account for about ~85% of the total production, and used for the purpose of this study.

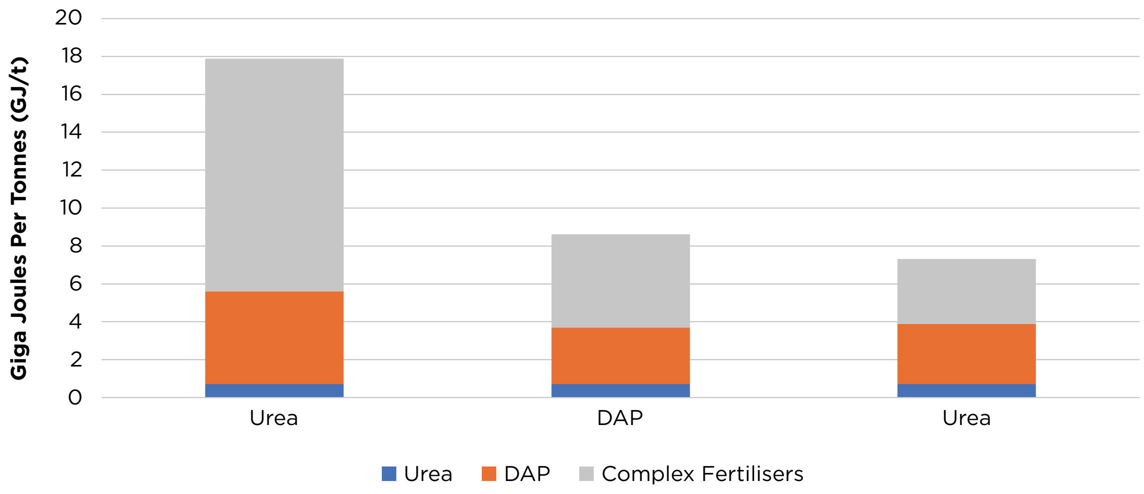

Figure 2.16: Estimated fuel-wise specific energy consumption of major Fertilisers

Key Policies and Initiatives for the Fertiliser Sector

Global Policies	Indian Policies
Global fertiliser policy is increasingly shaped by decarbonisation and clean hydrogen, as nitrogen fertilisers account for nearly 5% of global GHG emissions (IEA, 2023).	The Urea Policy (2015) and the Perform, Achieve and Trade (PAT) scheme have driven energy efficiency in urea production, delivering ~0.78 Mtoe energy savings in PAT Cycle 1 (BEE, 2017).
The EU's Carbon Border Adjustment Mechanism (CBAM) covers fertilisers such as ammonia and nitric acid, applying carbon costs on high-emission imports from 2026 (EC, 2023).	The National Green Hydrogen Mission prioritises fertiliser production for green hydrogen and green ammonia adoption, supporting pilot projects and future blending mandates (MNRE, 2023).
Countries are supporting green ammonia through clean hydrogen policies, initiatives such as Germany's H_2 Global and the U.S. Inflation Reduction Act are accelerating low-carbon fertiliser production (BMWK, 2023; US DOE, 2022).	The PM-PRANAM scheme incentivises states to reduce chemical fertiliser consumption by sharing 50% of subsidy savings to promote organic and bio-fertilisers (PIB, 2023).
Global initiatives like the Global Fertiliser Challenge launched at COP27 promote efficient fertiliser use and low-emission alternatives to strengthen food security while reducing emissions (US State Department, 2022).	Mandates such as Neem-Coated Urea and the promotion of nano-fertilisers aim to improve nutrient-use efficiency and reduce emissions from fertiliser use (MoC&F, 2015; IFFCO, 2023).

2.2.5 Textile sector

The global textile sector is vital to manufacturing, employment, and trade, employing over 75 million people and contributing USD 2.4 trillion to global manufacturing output. In 2022, fibre production reached 116 million tonnes, driven largely by the boom in fast fashion. Valued at USD 1.83 trillion in 2023, the industry is projected to grow at a CAGR of 7.4%, reaching USD 3.04 trillion by 2030. Asia dominates global production, with China, Bangladesh, and India together accounting for over 60% of global textile output (KPMG, 2021).

While textiles serve diverse applications including interior furnishings, automotive components, agri-textiles, and hygienic materials, clothing remains the primary driver of demand, accounting for 60% of total fibre consumption. China alone contributed to 35.6% of global textile exports in 2020, valued at USD 276 billion (Filho et al. 2022). India is the world's 6th largest exporter of textiles and apparel, with a 3.91% share in global trade 2023-24. Domestically, the sector contributes to 2.3% of GDP and 13% of industrial production, underscoring its strategic importance to the economy (PIB, 2025).

Textile production is highly energy and resource-intensive. Wet processing, including dyeing and chemical treatments, accounts for nearly 38% of total energy use (Minajigi, S.N., 2019). Globally, the sector contributed to around 10% of industrial emissions in 2022–23, releasing an estimated 1.7 billion tonnes of CO_2e (ILO 2022). In India, the sector emitted approximately 45 million tonnes of CO_2 in 2025 (estimated).

Globally, the industry is transitioning towards closed-loop production, CO_2-based waterless dyeing, and sustainable certifications such as OEKO-TEX, GOTS, and Bluesign. Circular business models and eco-labelling are becoming central to both brand strategy and regulatory compliance, reflecting rising consumer awareness and tightening environmental standards (Durand, 2025).

Textile Sector in India

India's textile and apparel industry is one of the country's oldest and most significant industrial sectors, contributing to around 2.3% of GDP and to over 12% of export earnings (PIB, 2025). It provides direct employment to more than 45 million people, making it the second-largest employer after agriculture (PIB, 2025). India's textile market, valued at USD 174 billion in 2023, is expected to grow at a CAGR of 11.98% to USD 350 billion by 2033, propelled by rising domestic consumption, growing export demand, and supportive policy initiatives such as the Production Linked Incentive (PLI) scheme. South and Southeast Asia are projected to remain the growth centres for global demand, buoyed by low labour costs, expanding e-commerce, and rising consumer interest in sustainable fabrics like organic cotton and recycled polyester (Ministry of Textiles, 2024).

With strong policy support, rising domestic demand, and expanding export opportunities, the industry has grown at an estimated 10.2% CAGR since 2016, positioning India as the world's second-largest textile producer and a major participant in global trade (at about 4% share) (IBEF, 2023; PIB, 2025). However, domestic textile consumption remains low at around 5 kg per capita annually, compared to the global average of 15 kg, indicating significant growth potential with rising incomes and urbanisation (Gupta, 2025).

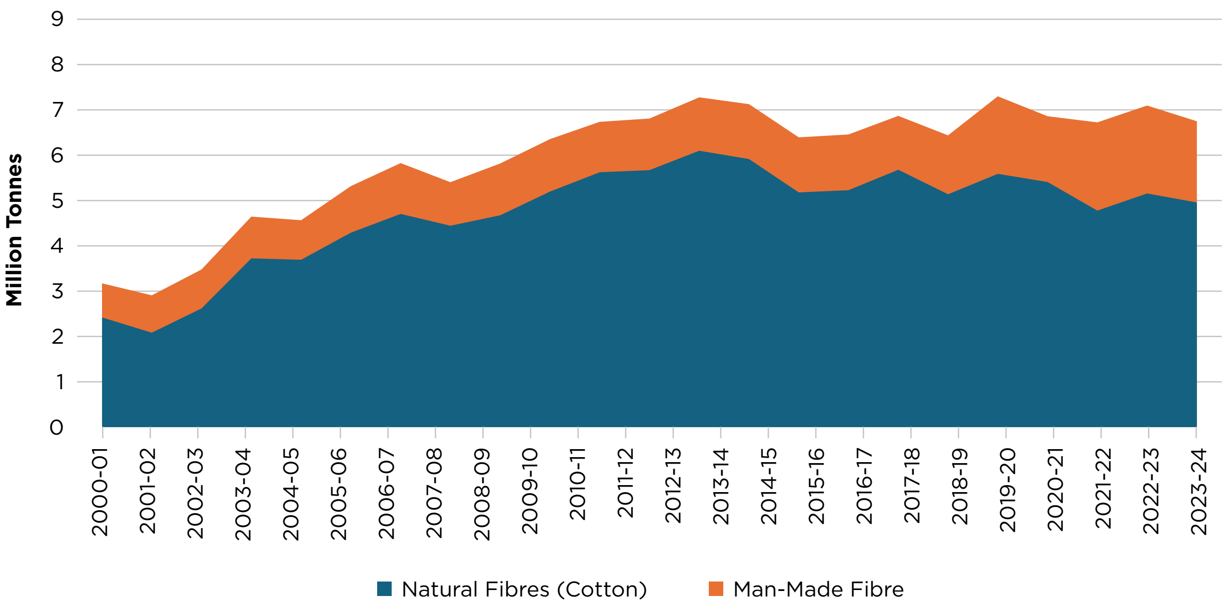

Figure 2.17: Historical production of textile, (million tonnes)

Historically, India's textile base has been dominated by cotton, with cotton fibre accounting for 75–80% of total fibre consumption in the past. However, a structural shift toward man-made fibres (MMFs) such as polyester, viscose, and technical textiles is underway. By 2022–23, MMFs made up about 27% of domestic fibre output, up from 19% in 2016–17, reflecting diversification toward more durable, affordable, and performance-oriented materials. This transition aligns with global trends, where synthetics account for 72% of fibre consumption. While this shift supports export competitiveness, it also raises energy and emissions intensity, as MMF production requires higher energy inputs and dependent on petrochemical feedstocks, in contrast to cotton's lower footprint as an agricultural resource (UNCTAD, 2025; IBEF, 2023).

Structurally, the sector is highly fragmented and decentralised, comprising a mix of large integrated mills and a vast number of MSMEs engaging in spinning, weaving, knitting, dyeing, and garment manufacturing. Around 95% of fabric production comes from small and informal units, which account for about 80% of installed capacity located in clusters such as Surat (synthetics), Tirupur (knitwear), and Ludhiana (woollens) (Gupta, 2020). While this fragmentation provides broad employment, it also constrains technology modernisation and energy efficiency upgrades, as smaller enterprises often rely on outdated equipment, automate less, and rely on fossil-fuel-based heat sources.

The sector's final energy consumption (accounting for electricity generation from captive power plants rather than associated fuel consumption) has risen from 6.6 Mtoe in 2020 to 8 Mtoe in 2025. Among processes, finishing (which includes dyeing, drying, and washing) is the most energy-intensive stage, consuming about 43% of total energy, of which 73% is met by coal. Spinning accounts for roughly 24% of energy use, and is largely electricity-driven (72%), while weaving and knitting together represent around 15% energy consumption, mainly based on electricity (Vasudha Foundation, 2025). Accordingly, the fuel mix comprises 42% coal, 40% grid electricity, and 12% biomass (see Figure 2.18).

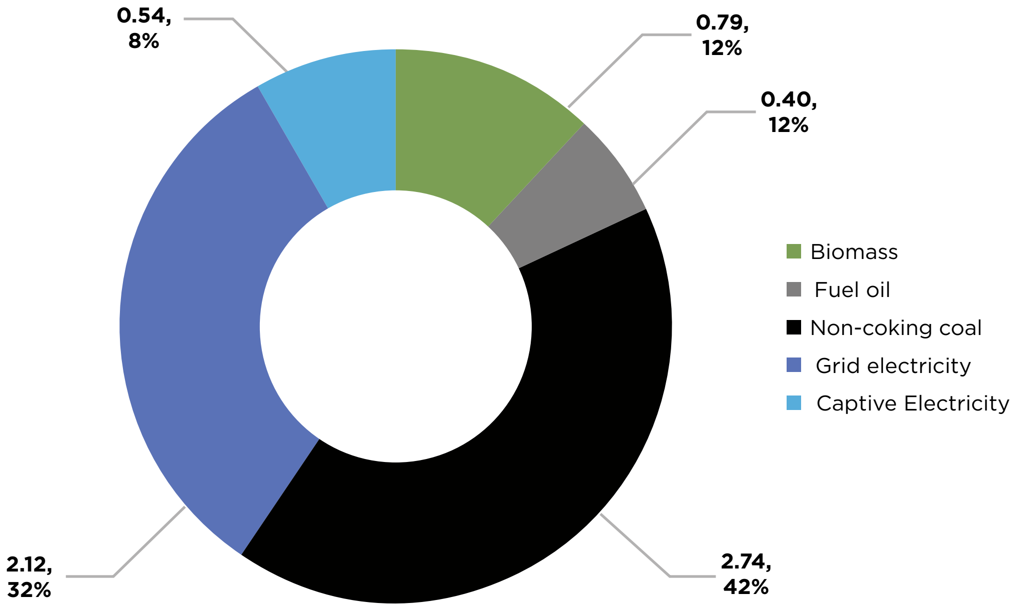

Figure 2.18: Energy mix (Mtoe, %) in textile sector

Beyond CO_2, textile processing generates substantial wastewater and chemical pollution, particularly from dyeing operations. Addressing energy efficiency, fuel switching, and cleaner production technologies will be crucial to ensure sustainable growth as domestic and export demand continue to rise.

Technological innovation is transforming the industry. Globally, players are adopting Industry 4.0 solutions such as digital printing, AI-enabled quality control, and IoT-driven production optimisation. India has seen similar progress, particularly among large and export-oriented enterprises. However, the sector remains largely composed of MSMEs, many of which operate informally in clusters like Surat, Tiruppur, and Panipat. These units continue to rely on outdated technologies and manual processes, limiting their productivity and environmental performance.

To address this, the Government of India has launched the National Technical Textiles Mission to foster innovation and investment in high-performance textiles, including agro-textiles, medical textiles, and protective gear, positioning India as a global hub for technical textiles (Ministry of Textiles 2022). Environmental stewardship is also being promoted through targeted schemes. The Ministry of MSME's Zero Defect Zero Effect (ZED) certification encourages small manufacturers to adopt cleaner production and resource-efficient practices (MoMSME). In major clusters like Tiruppur and Surat, collective mitigation efforts such as Common Effluent Treatment Plants (CETPs) are supporting compliance with pollution control norms.

Key Policies

The textile industry consumes about 1.2 million tonnes of oil equivalent in energy annually (Gunturu 2022). Several policies like the PAT scheme were implemented, resulting in 0.33 Mtoe of energy saved between 2012 and 2022 (BUR 4 Report 2024). A push for renewable energy adoption is driving further efforts to decarbonise the sector. India is also accelerating sustainable transformation through flagship initiatives. The PM MITRA scheme establishes integrated textile parks with common effluent treatment plants and renewable energy supply to reduce the environmental footprint.

Global Policies	Indian Policies
EU adopted a Strategy for Sustainable and Circular Textiles (2022) aimed at making textiles durable, repairable and recyclable by 2030 – including eco-design requirements, minimum recycled fibre content, and mandatory Extended Producer Responsibility for textile manufacturers. Further, the EU has introduced European Sustainability Reporting Standards (ESRS) and Ecodesign for Sustainable Products Regulation (ESPR) to incentivise durable and recyclable textiles that can promote the circular economy (Alchemie 2024).	The Ministry of Textiles has established an Environmental, Social, and Governance (ESG) Task Force to guide the sector toward sustainable practices, including recycling and resource efficiency (Outlook 2024). The National Technical Textile Mission (NTTM) aims to promote innovation in high-performance and durable textiles, supporting sustainability and global competitiveness. The Textile Policy 2024 aims to modernise the textile sector, promote sustainability, foster innovation, and expand India's presence in global markets.
California's Responsible Textile Recovery Act mandates the recycling of textiles. France's Anti-Waste Law for a Circular Economy (2020) bans the destruction of unsold clothing. Several countries have textile labelling policies (the EU's Digital Product Passport), creating demand-side pressure for sustainable production, with increasing robustness of standards to prevent greenwashing.	Green financing from SIDBI and IREDA enables MSMEs to access capital for energy-efficient technologies and renewable energy integration. Maharashtra government's Integrated and Sustainable Textile Industry Policy (2023-28) (GoM, 2023) offers capital subsidies to textile units for setting up solar power projects, promoting renewable energy adoption within the industry.

2.2.6 Paper & Pulp

India's paper and pulp industry plays a vital role in supporting sectors such as education, publishing, packaging, and sanitation. India is among the top 5 paper-producing countries globally (CPPRI, 2022). The sector is highly fragmented, comprising large integrated mills, medium-sized mills, and numerous small units. India has over 900 paper units with an installed capacity of nearly 29.11 million tonnes, of which around 538 mills are operational with a total operating capacity of approximately 25.28 million tonnes (CPPRI, 2022). In 2021–22, actual production was around 22.43 million tonnes (NITI Aayog). As shown, total paper and pulp output grew at a CAGR of 5.4% between 2010–11 and 2021–22 (Figure 2.19), with production dominated by Recycled Fibres (RCF)-based mills (75%), followed by Wood-based (19%) and Agro-based (6%) routes (IPMA).

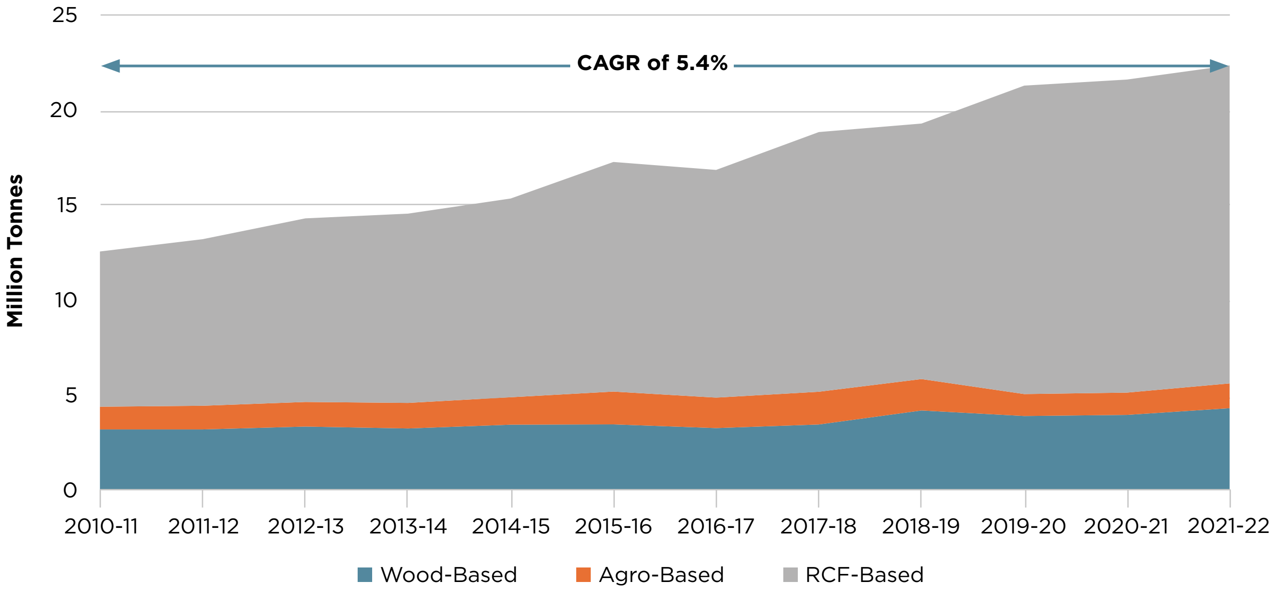

Figure 2.19: Historical production of paper and pulp through different routes (million tonnes)

With India's per capita paper consumption (around 16 kg/capita) significantly below the global average (around 57 kg/capita), the market offers substantial room for expansion. Packaging paper and board, in particular, have emerged as the fastest-growing segments due to the rise of online retail and food delivery services. To meet this demand, several mills have expanded capacities and invested in modern technologies.

However, this growth has also increased pressure on natural resources, especially in terms of energy, water, and raw materials. The industry is energy- and water-intensive, traditionally reliant on coal-based captive power and virgin raw materials like wood and agro-residues. In terms of average energy consumption, wood-based and agro-based paper production consume similar thermal energy of 27.3 GJ/t, with electrical energy use of 5.22 GJ/t and 4.5 GJ/t, respectively, while RCF-based production is significantly less energy-intensive, requiring only 11.3 GJ/t of thermal and 2.61 GJ/t of electrical energy (Figure 2.20) (Shakti Foundation).

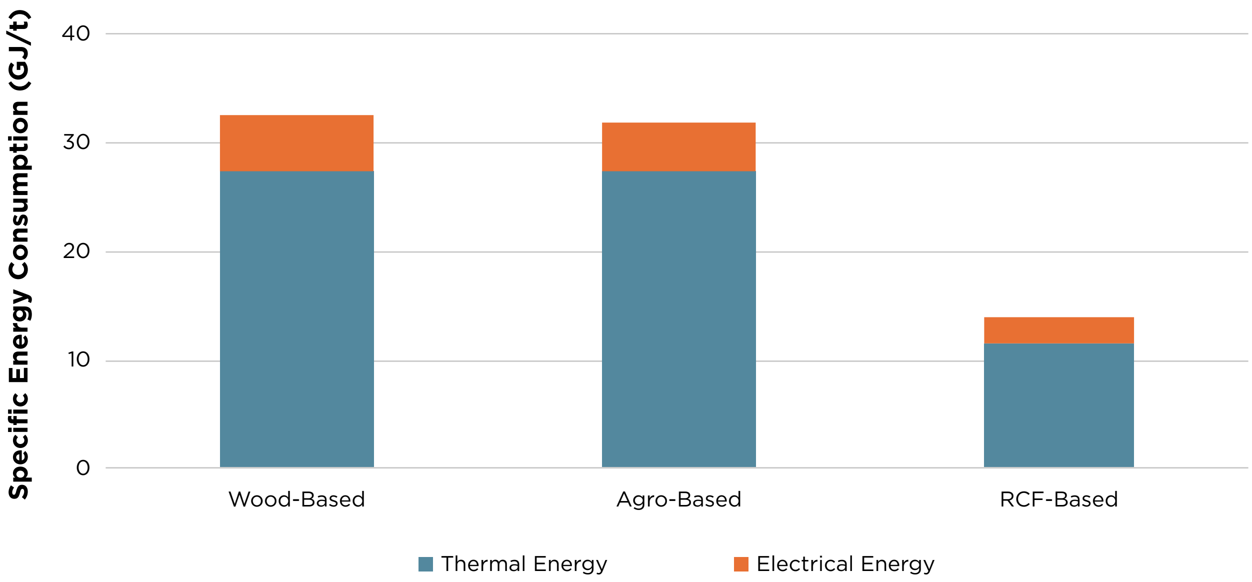

Figure 2.20: Estimated specific energy consumption of paper and pulp industry[6] (GJ/t)

2.2.7 Ethylene

Petrochemicals are energy-intensive and contribute significantly to environmental pollution and greenhouse gas (GHG) emissions. Globally, the petrochemical sector has a significant carbon footprint, accounting for about 17% of industrial carbon-dioxide emissions (Cullen et al., 2022). While these emissions come from chemical reactions, high-temperature heat generation, energy conversion processes, and end-of-life treatments, additional emissions are also produced during the use phase and from upstream oil and gas operations. Naphtha and natural gas are important feedstocks for manufacturing petrochemicals.

In India, the petrochemical sector has witnessed exponential growth. Considering the diversity and complexity of the petrochemical industry, this study is focused on ethylene, which is the basic chemical building block for daily-use products, such as plastics and textiles. Ethylene is produced conventionally through the steam-cracking process from a range of hydrocarbon feedstocks like naphtha and ethane. Steam cracking is a highly endothermic process, requiring a significant input of heat, typically reaching temperatures around 750°C to 900°C, to break down large hydrocarbon molecules into smaller ethylene and propylene molecules (Haribal, 2018). This makes steam cracking one of the most energy-consuming processes in the petrochemical industry.

In the last 21 years (from 2002-03 to 2023-24), ethylene production in India grew at a CAGR of approximately 4.7%, driven by increasing domestic demand for downstream products such as plastics, packaging materials, synthetic fibres, and chemicals. Total ethylene production in 2023-24 was approximately six million tonnes; however, per capita production was only about 4.5 kg, compared to the global average of approximately 28 kg per capita (Department of Chemicals and Petrochemicals, Ministry of Chemicals and Fertilisers, 2025).

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[6] Estimated based on the mix of grid electricity and fuel required for the thermal energy and captive electricity for different technology type.

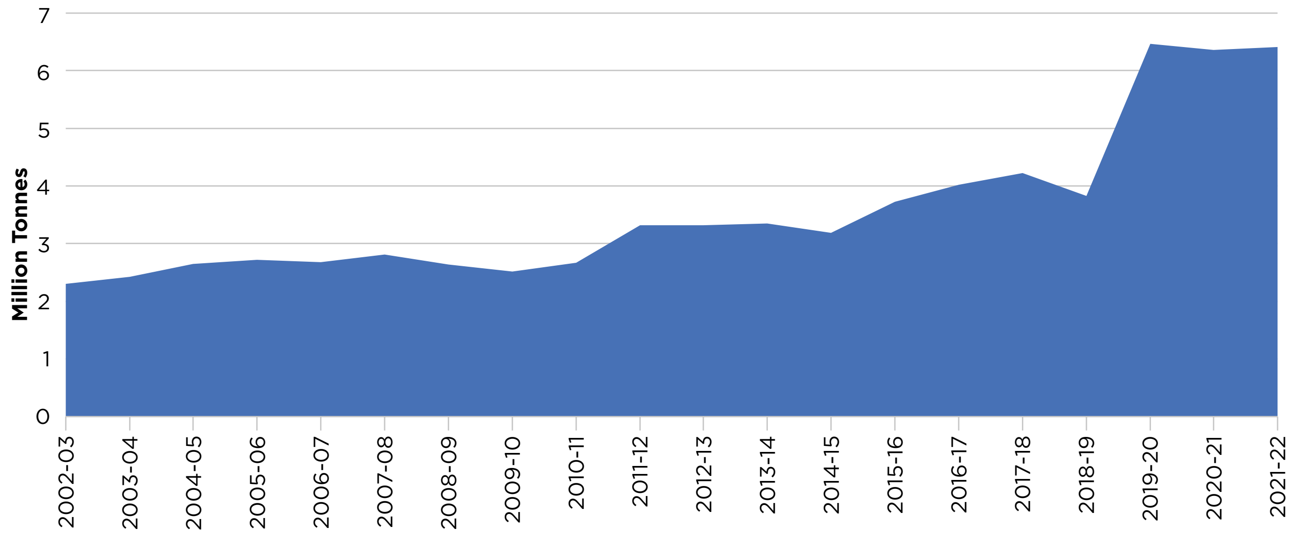

Figure 2.21: Historical production of ethylene (million tonnes)

Specific Energy Consumption

The naphtha route accounts for around 44% and the ethane route for about 55% of current ethylene production. The naphtha route for ethylene production consumes 25.7 GJ/t of thermal energy, 0.6 GJ/t of electrical energy, and 148.53 GJ/t from feedstock. The ethane route requires 17 GJ/t of thermal energy, 0.7 GJ/t of electrical energy, and 62.4 GJ/t from feedstock[7] (Figure 2.22).

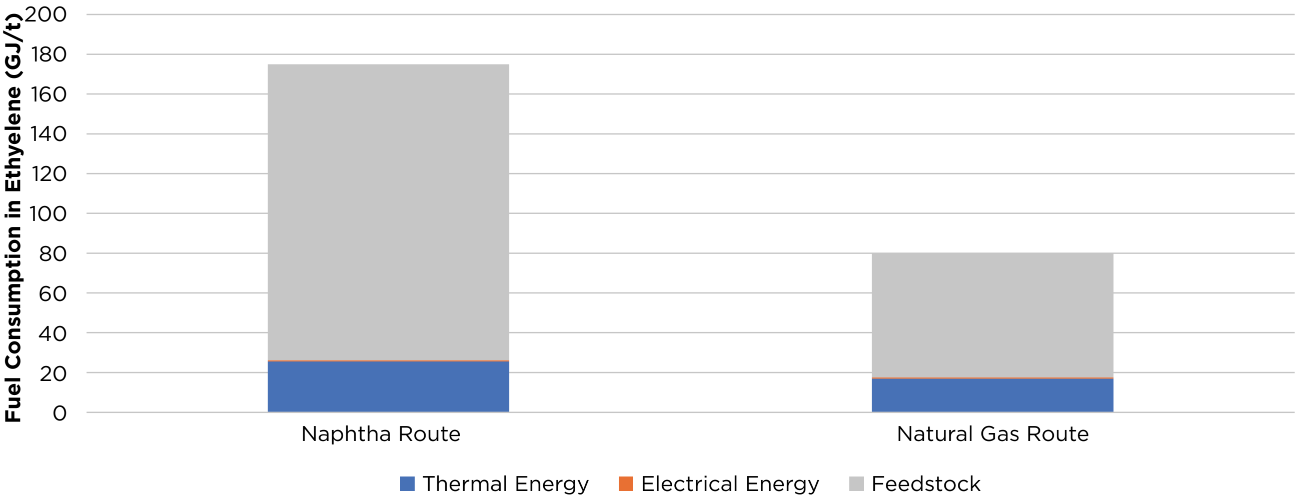

Figure 2.22: Estimated fuel consumption in ethylene production (GJ/t)

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[7] Based on Industry consultation

2.2.8 Chlor-Alkali

The chlor-alkali industry is a cornerstone of the global chemical sector, enabling a broad spectrum of industrial and consumer applications through the production of key inorganic chemicals such as caustic soda (sodium hydroxide), soda ash (sodium carbonate), and liquid chlorine. These chemicals are critical inputs across various sectors. Caustic soda is used extensively in alumina refining, paper and pulp production, textiles, soaps and detergents, and water treatment. Soda ash serves as a key raw material in the manufacture of glass, synthetic detergents, and sodium-based chemicals, and is also used in water softening. Liquid chlorine is used in the production of PVC, chlorinated solvents, bleaching agents, disinfectants, and plays a crucial role in water purification and sanitation.

Globally, the chlor-alkali sector produces over 80 million tonnes of caustic soda and over 70 million tonnes of soda ash annually, with significant concentration in regions like China, the U.S., and the EU (Prismane Consulting, 2025). India is among the top five producers of chlor-alkali products, with caustic soda production over 3.6 million tonnes in 2024 and soda ash production at approximately 2.9 million tonnes (Department of Chemicals and Petrochemicals, Ministry of Chemicals and Fertilisers, 2025). Liquid chlorine, a byproduct in caustic soda production, is also produced in significant quantities and plays a vital role in multiple downstream industries. The production of one tonne of caustic soda typically yields around 0.7 tonnes of chlorine, usually in liquid form (BEE). Figure 2.23 presents the historical production of Chlor-Alkali products in India. In last twenty two years (from 2001-02 to 2023-24), Caustic Soda demand grew at 3.9% CAGR due to its rising use in textiles, alumina, and water treatment, supported by urbanisation and industrial expansion. Soda ash grew at a CAGR of 2.2%, driven by consistent demand from glass, detergent, and chemical industries.

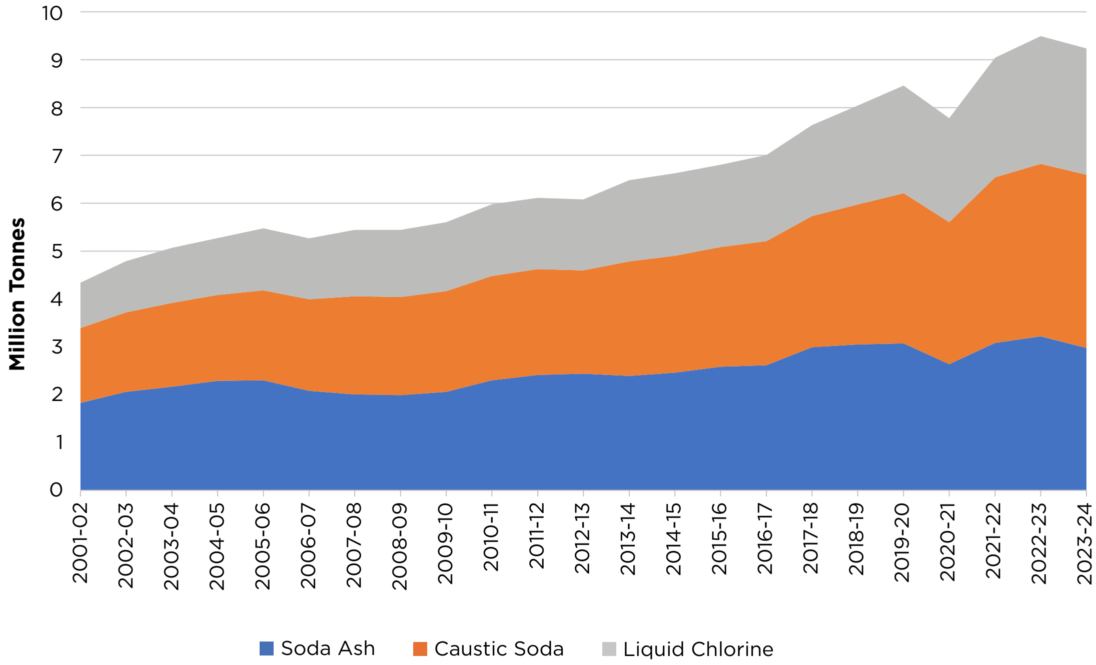


Figure 2.23: Historical production of chlor-alkali products (million tonnes)

Caustic Soda industry also saw a huge transformation from mercury to membrane technology (Electrolysis of brine), which is eco-friendly and energy efficient (UN Environment, 2017). In this process, almost 70% energy is consumed by the electrolyser (BEE). In Caustic Soda production, the share of thermal energy is 42% with rest being electric. In case of Soda Ash, which uses solvay and dry lime process for production, the share of thermal energy is ~94% .

The average specific energy consumption in 2025 for Soda ash is 8.54 GJ/t (8.00 GJ/t thermal and 0.54 GJ/t electrical), while the same for caustic soda is 15.50 GJ/t (comprising 6.50 GJ/t thermal and 9.00 GJ/t electrical), as shown in Figure 2.24.

Low-carbon transition of the Indian chlor-alkali sector includes phasing out mercury-based technology through a shift to membrane-based technology, improving process automation, energy efficiency and electrification using renewable energy. As India pursues self-reliance in chemicals manufacturing under initiatives like Make in India and Aatmanirbhar Bharat, the chlor-alkali sector is set to play a central role in meeting domestic industrial needs while transitioning toward a more sustainable and circular production model.

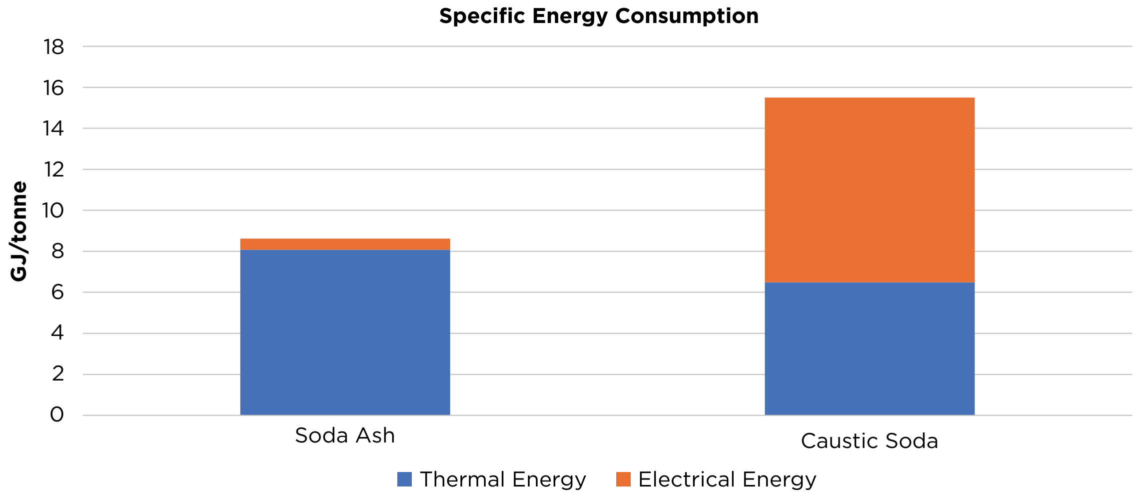


Figure 2.24: Estimated specific energy consumption in chlor-alkali products (GJ/t)

While green hydrogen-based ammonia offers transformative potential, the carbon requirement in urea synthesis complicates a complete transition. Still, adopting green ammonia, especially with external CO_2 sourcing, could make the industry net carbon-negative.

2.2.9 Refinery

India is heavily reliant on imported crude oil to meet its energy demands, importing over 87% of its crude oil requirements. In 2023-2024, India imported approximately 234 million tonnes (Mt) of crude oil, primarily from Iraq, Saudi Arabia, Russia, and the UAE. However, in the refining sector, India has steadily positioned itself as one of the world's leading refining hubs. As of 2025, India operates a refining capacity of about 258 million tonnes per annum (Mtpa), equivalent to about 5 million barrels per day. This places it as the fourth-largest refining country globally, after the United States, China, and Russia. As shown in Figure 2.25, the refinery capacity in the last 23 years has grown with a CAGR of 3.6% (PPAC; PIB, 2025).

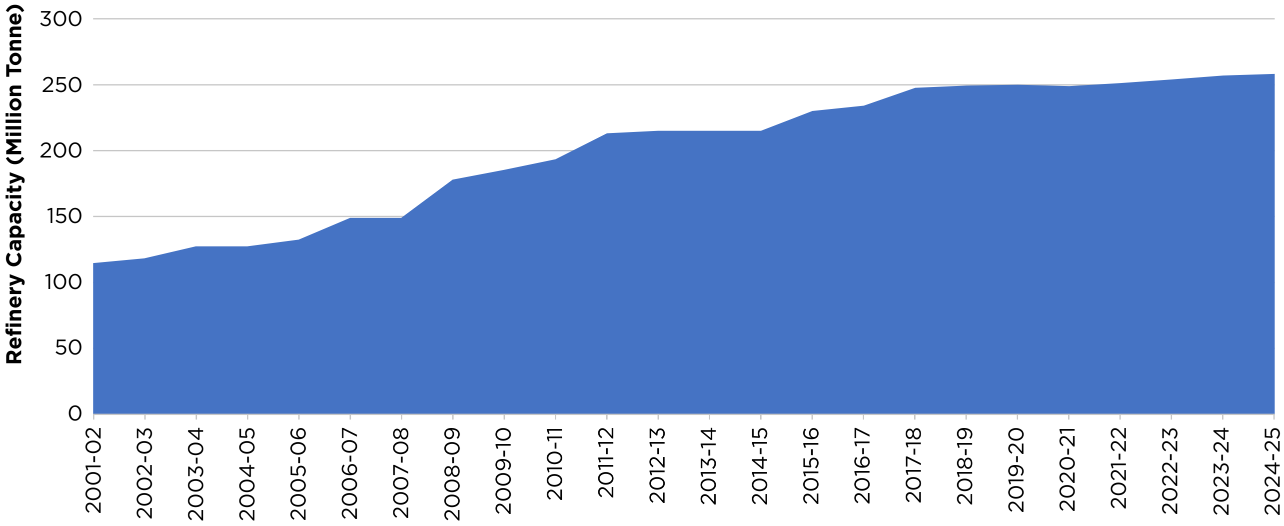


Figure 2.25: Historical trend of refining capacity in India (million tonnes)

Indian refineries process a broad range of crude qualities and maintain relatively high levels of capacity utilisation, averaging over 90%, which is significantly above the global average (PIB, 2025). This operational efficiency, combined with a growing domestic demand for transport fuels and petrochemicals, has made India one of the few countries where refining capacity continues to expand even as the global refining industry contracts in response to the energy transition. Figure 2.26 shows the historical trend of production of various petroleum products in India.

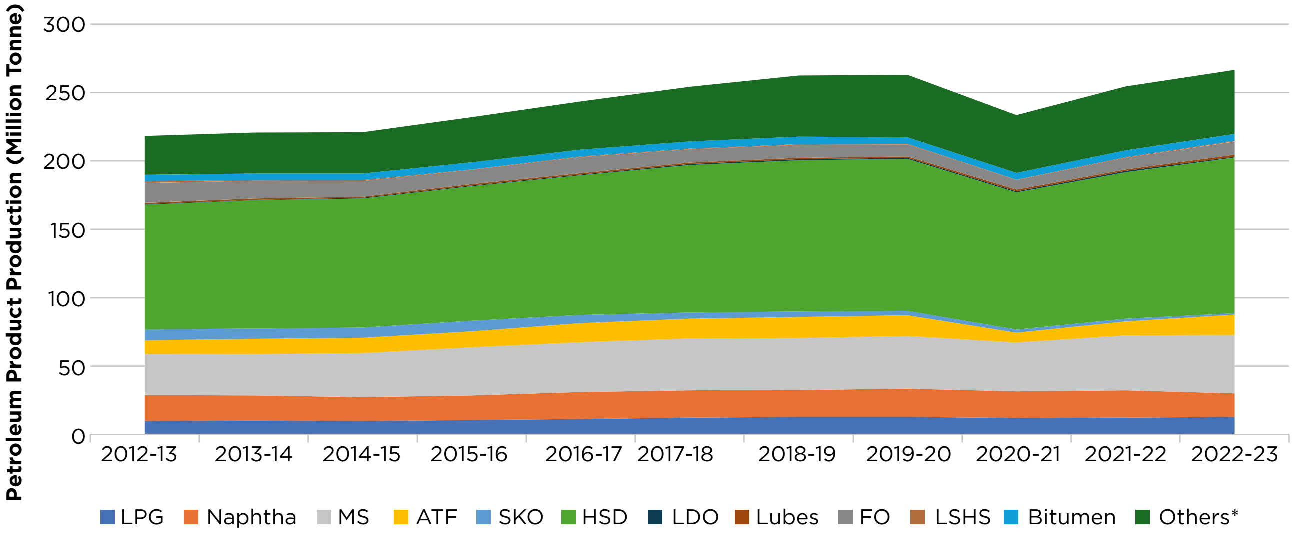


Figure 2.26: Historical production of various petroleum products (million tonnes)

Equivalency factors considered in this study for the conversion of crude oil to oil products (Diesel, Petrol, ATF, LPG, Petcoke, Fuel oil, Naphtha, Kerosene) are provided in Annexure-VI.

Despite its growth, the sector faces significant sustainability and climate-related challenges. India's refining sector accounted for roughly 2.8% of the country's total greenhouse gas (GHG) emissions in 2020. As refinery throughput grows, these emissions are expected to rise if no mitigation strategies are deployed. One of the major contributors to these emissions is the widespread use of grey hydrogen, produced from steam methane reforming (SMR), for refinery processes such as hydrocracking and desulphurisation.

Specific Energy Consumption

The Indian refinery industry is among the energy-intensive sectors due to the processing of heavier and more complex crude slates. The electricity and steam consumption of refineries typically accounts for 1.6 GJ/t of crude oil processed. In addition to electricity, hydrogen consumption is a critical component of refinery energy use, averaging 8-8.5 kg of hydrogen (0.95 GJ) per tonne of crude oil, depending on the degree of refinery integration and complexity. Higher hydrogen demand is driven by extensive use of hydrotreating and hydrocracking units, which are necessary to remove sulphur and other impurities.

Beyond electricity and hydrogen, refineries also consume substantial thermal energy, amounting to approximately 1.47 GJ/t of crude oil processed, largely for process heating and steam generation. Steam used in refineries is obtained from co-generation in power plants. At present, a significant share of this electricity, steam, and thermal energy demand is met through internal energy sources, including the combustion of refinery fuel gas, purge gas, synthesis gas from grey hydrogen production, and other own petroleum products in captive power plants, boilers, and furnaces. The consumption of electricity, hydrogen and thermal energy tend to increase with deeper conversion, higher product quality requirements, and greater integration of refining and petrochemical operations. Figure 2.27 shows the electricity and thermal energy consumption from various fuels and hydrogen consumed for each metric tonne of crude oil processed.

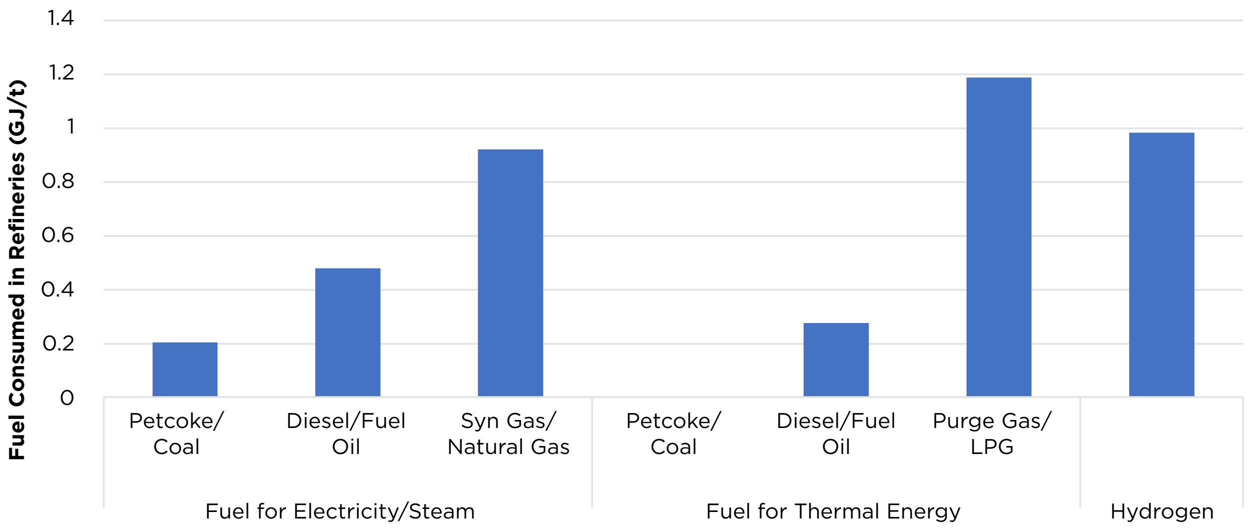


Figure 2.27: Fuel consumption in refinery sector in India (GJ/t)

The key elements to decarbonise this sector include the gradual replacement of grey hydrogen with green hydrogen, produced through water electrolysis powered by renewable energy. The sector is also focusing on increasing energy efficiency, deploying carbon capture, utilisation, and storage (CCUS) technologies, and integrating renewable energy into refinery operations.

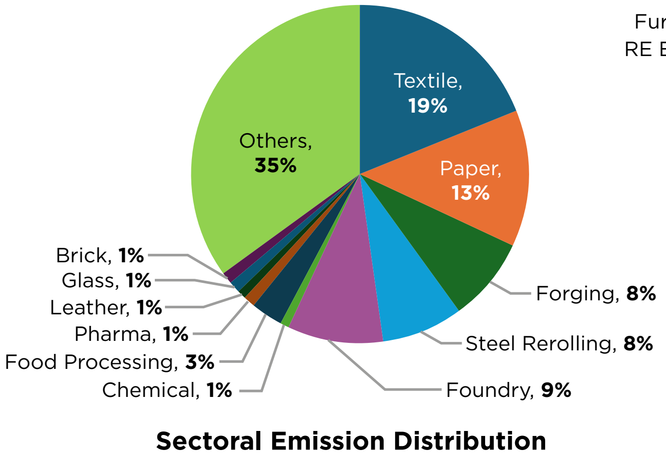
2.2.10 Other Energy-Intensive Sectors: MSME sector

Following key industrial sectors like steel, cement, aluminium, fertilisers, and textiles, Micro, Small, and Medium Enterprises (MSMEs) represent a significant and diverse segment of India's industrial landscape. Globally, MSMEs span energy-intensive sub-sectors including textiles, pulp and paper, chemicals, bricks, glass, pharmaceuticals, leather, food processing, forging, and foundries, all of which contribute notably to industrial emissions.

MSMEs comprise 90% of all businesses worldwide, contribute to 50% of global GDP, and provide 70% of global business-sector employment (ICSB 2024). In advanced economies, MSMEs account for 80% of employment in professional services and 92% in construction, while contributing relatively less to value addition. In emerging economies, they dominate trade (83% of employment) and manufacturing (71%), playing a vital role in job creation despite limited value capture (McKinsey 2024).

India is home to an estimated 63.3 million MSMEs, accounting for 30.1% of GDP, over 250 million jobs, and 45.7% of the country's exports. The manufacturing MSMEs alone employ 36 million people across nearly 20 million units, representing 57% of all manufacturing employment (FICCI, 2023; MoMSME, 2024). The sector also contributes to approximately 25% of industrial energy consumption and emits an estimated 135 million tonnes of CO_2 in 2022 (FICCI, 2023; MoMSME, 2024).

Textiles (19%), paper (13%), steel re-rolling (8%), forging (8%), and foundries (9%) collectively account for nearly 60% of MSME emissions (Figure 2.28). Less prominent sub-sectors, including chemicals, pharmaceuticals, and leather, contribute another 35%. Fuel-wise, emissions are primarily driven by electricity (47%) and coal (43%), which together account for 90% of total emissions. The continued use of outdated equipment, such as inefficient furnaces, motors, and boilers, significantly worsens the sector's carbon footprint (BEE, 2019).



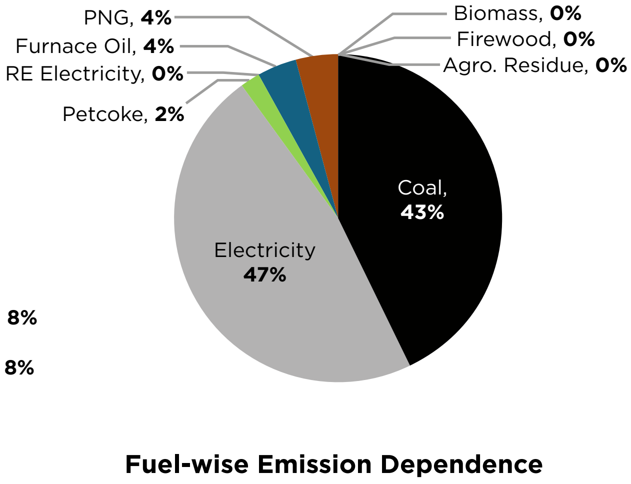


Figure 2.28: Emission distribution across Indian MSME sectors

Source: *(BEE, 2018)*

Globally, enterprises with 5–99 employees generate over half of net employment creation. However, despite their economic significance, MSMEs' environmental footprint remains poorly documented. Existing evidence indicates they account for a sizable share of global carbon emissions and energy use. For instance, SMEs generate 63% of business-driven direct carbon emissions in the EU (OECD 2023), while the OECD estimates that SMEs consume 13% of global energy and one-third of industrial and service-sector energy (OECD 2023).

In India, cost considerations often overshadow environmental concerns. As a result, investments in energy efficiency, renewable energy, or pollution control are typically deprioritised. However, low-carbon transition, particularly through reduced fossil fuel consumption, offers dual benefits of emissions reduction and cost savings. Implementing energy-efficient (EE) technologies can enhance competitiveness, improve energy security, and reduce operational costs (TERI, 2022).

Recognised as the "first fuel" of clean energy transitions, energy efficiency offers quick, cost-effective mitigation of CO_2 emissions. Technology upgrades and operational improvements can lower both emissions and energy intensity. Several incentives, including accelerated depreciation and credit-linked subsidies, are available to MSMEs investing in EE technologies, with payback periods ranging from one to 5 years. In addition, switching to cleaner fuels such as biomass, biofuels, LPG, PNG, and adopting process electrification can reduce dependence on grid electricity and high-emission fuels like diesel (Ministry of Power, 2025; IEA, 2025).

Government efforts at the central and state levels have introduced multiple schemes to support MSME transition, ranging from financial assistance to resource efficiency programs (MoMSME 2022; MoMSME):

- **Financial Assistance:**
    - **MSE GIFT (Green Investment and Financing for Transformation):** provide concessional finance to MSME for adopting green technologies such as solar roof top, solar pumps, small hybrid solar-wind system, small off-grid wind system, and waste management, biogas plants from organic waste, etc.
    - **CGTMSE/CGSS (Credit Guarantee Fund Trust for Micro and Small Enterprises/ Credit Guarantee Scheme for Startups):** facilitates collateral-free credits to Micro and Small Enterprises by providing guarantee cover.
- **Resource Efficiency**
    - **MSE SPICE (Scheme for Promotion and Investment in Circular Economy):** empowers MSEs to adopt sustainable, resource-efficient and eco-friendly practices.
- **Digital Transformation**
    - **Trade Receivables Discounting System (TReDS):** an electronic platform, regulated by RBI, to help MSMEs convert their unpaid invoices into cash by connecting them to multiple financiers.

Adoption of greener technologies and fuels not only enables access to low-carbon markets but also promotes inclusive economic growth through higher profits, business expansion, and employment generation.

Targeted interventions to reduce MSMEs' Scope 1 and Scope 2 emissions are critical. Enhancing energy efficiency, increasing green electricity uptake, and transitioning to alternative fuels can serve as key levers. However, low adoption persists due to multiple challenges, including limited technical capacity, constrained manpower, and a predominant focus on production and marketing. MSMEs require external support to access cutting-edge technologies, technical know-how, and proven best practices. Figure 2.29 outlines the key barriers to energy efficiency and clean energy adoption in India's MSME sector (Mitra, 2023).

Energy Efficiency	Green Electricity (GE)	Alternate Fuel (AF)
Lack of Trust in ecosystem: MSMEs fail to collaborate with ESCO despite performance guarantees due to lack of trust/understanding of such mechanism. **Awareness and Capacity to implement latest technology:** MSMEs are unaware of the technologies and performance guarantee models run by energy services companies.	**Perceived risk of payment default by MSMEs:** RESCOs require risk of extending services to MSMEs to be mitigated due to perceived payment defaults. **Stakeholder support:** State DISCOMs are required to extend timely support to the ecosystem to get such renewable power plants online.	**Awareness on various agro feed:** MSMEs are typically unaware of the possible agro residues that can be made into brickettes and pellets for biomass firing. **Scalability Issues:** Many biofuels and products are perishable and thus have lower shelf life making it challenging for logistics. Further, seasonality factors that impact availability and many potentially lead to fuel shortage

Figure 2.29: Key barriers to MSME adoption of sustainable energy solutions

Source: *(Mitra, 2023); (Mori, 2024); (CSTEP, 2024); (TERI, 2020)*

2.3 LOW-CARBON TRANSITION LEVERS

Globally and in India, industrial low-carbon transition is advancing through key interventions: energy and material efficiency, non-fossil electricity, green procurement mandates (including green public procurement), process electrification, alternative fuels, technological innovation, and carbon capture, utilisation, and storage (CCUS). These levers are gaining traction across sectors and have been supported by a range of policy instruments that focus on balancing energy security, industrial competitiveness, and environmental sustainability. These efforts are intended to promote technology adoption at both the MSME and large-industry levels.

The sections below highlight select technologies currently central to global and Indian transition pathways, along with high-impact policies under each low-carbon transition lever.

2.3.1 Energy Efficiency[8]

Energy efficiency remains a foundational strategy for industrial low-carbon transition. In India, the Bureau of Energy Efficiency (BEE), under the Ministry of Power, launched the Perform, Achieve and Trade (PAT) scheme to accelerate the adoption of energy-efficient technologies in energy-intensive sectors.

Initial PAT phases established sectoral baselines and benchmarked performance against global standards. Energy audits and technical studies at Designated Consumer (DC) levels identified targeted interventions, leading to widespread adoption of efficient technologies, many of which were developed indigenously. Having implemented early, multi-sectoral interventions, India has closed a significant portion of the low-hanging energy performance gap. By the end of PAT

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[8] BEE Reports

Cycle VI, cumulative CO$_2$ savings exceeded 110 million tonnes. The focus now shifts to wider adoption of efficiency and to driving deeper, harder-to-abate efficiency improvements that require sustained investments, technical support, and policy incentives (BEE, 2023).

Table 2.2: Summary of energy savings (BEE, 2023-24)

Program/ Scheme	Sector	Electricity Savings (BU)	Total Energy Savings (Mtoe)	GHG Reduction (MtCO$_2$)	Monetary Savings (INR Crore)
PART - VI	Large Industry	-	1.3	4.5	-
PAT - V		0.008	0.68	3	1256
PAT - IV		0.009	0.75	3	1385
PAT - III		0.62	2	5.59	3223
PAT - II		36	14	69	43078
PAT - I		3	8.67	31	9500
BEE - GIZ	MSME	0.0	0.0	0.0	0.74
ECBC	Commercial Building	0.64	0.36	0.53	102
BEE Star Rating					
GRIHA					
ENS	Residential Buildings				
S&L	Appliances	89	8	63	56535
UJALA	LED Lamps	182	15	130	72800
SLNP	Municipal	9	0.76	6	5535
CAFE-I	Transport		2	6	6795
Total		**321.39**	**53.60**	**321.06**	**200212.84**

Table 2.3: Policy instruments supporting energy efficiency in industry

Policy / Scheme	Applicability	Administering Body	Details
Perform, Achieve and Trade (PAT) (BEE 2020)	Energy-intensive sectors like steel, cement, aluminium, textiles, paper	BEE, MoP	Cap-and-trade scheme to reduce specific energy consumption; enables trading of Energy Saving Certificates.
Energy Efficiency Financing Platform (EEFP) (BEE 2023)	MSMEs and large industries across sectors	BEE, SIDBI, IREDA	Platform to ease financing for EE projects via standardisation and risk-sharing mechanisms.

Policy / Scheme	Applicability	Administering Body	Details
Promoting energy efficiency and renewable energy in selected MSME clusters in India (BEE 2023)	MSME clusters in engineering, food processing, ceramics, etc.	UNIDO, BEE, GEF	Capacity building and implementation support to MSMEs for energy-efficient technologies.
Credit Linked Capital Subsidy and Technology Upgradation Scheme (CLCS-TUS) (MoMSME 2023)	Small and medium industries in high energy-use sectors	MoMSME, BEE	Supports modernisation of technologies in SMEs for improved energy performance.
Custom Industrial Pilots (e.g., UNIDO-BEE MSME demo projects)	Sector-specific (foundries, ceramics)	MoMSME, BEE, UNIDO	Demonstrated the feasibility of electric heating and drying systems, but not scaled via policy yet.

2.3.2 Electrification

Industrial heat generation accounts for 20% of global energy demand and is a major source of emissions. Fossil fuels dominate the process heat mix, with electricity comprising just 11%. However, about 45% of industrial heat demand is in the low-temperature range (<200°C), presenting a significant electrification opportunity (Figure 2.30) (IEA, 2018).

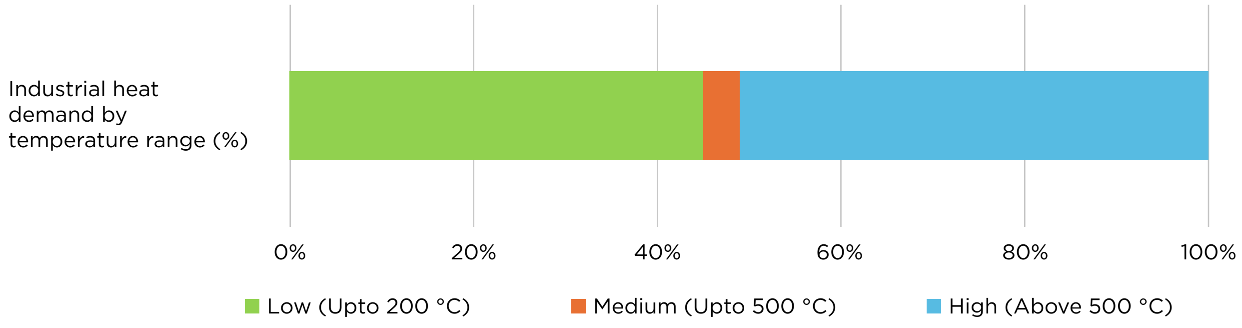

Figure 2.30: Global industrial heat demand across low, medium, and high temperature ranges

Source: *(IEA, 2018)*

Emerging electric heating technologies cater to varied temperature needs. For low- to mid-range applications (200°–500°C), MSMEs in food processing, textiles, and pulp and paper are adopting heat pumps, Mechanical Vapour Recompression (MVR), and electric boilers. High-temperature technologies like turbo and induction heaters can exceed 1,000°C. The economic attractiveness of these technologies is rising in regions with high gas prices and carbon pricing (BEE).

Table 2.4: Temperature range of potential electric heating technologies

Temperature Range (°C)	Potential Electric Heating Technologies
Up to 200	Heat Pump, Electric Boilers
Up to 500	Electric boilers, Combined Thermal storage systems, Resistance heating, Process Air Heaters
Beyond 500	Induction heating, Plasma torches, Electric arc furnaces, Shockwave heating, RotoDynamic Heaters (RDH)

India is promoting such technologies under BEE initiatives, listing electric boilers and process upgrades as recognised efficiency measures. While arc furnaces are exceptions, electricity remains underutilised for process heat due to higher levelised costs relative to fossil fuels (MoP 2024).

Box-7: Case Study: Heat Pump Replacing Gas Boiler in a Dairy facility[9]

Heat pumps are increasingly being recognised as a viable solution for electrifying low- to medium-temperature industrial heat applications. Their ability to utilise ambient or waste heat sources and convert them efficiently into process steam makes them particularly attractive for sectors such as food processing and dairy. A notable example comes from Norway, where Olvondo Technology collaborated with a dairy factory to replace gas-fired steam boilers that previously consumed 21.1 GWh of electricity annually. The company installed four high-temperature HighLift heat pumps that used a 25°C waste heat source to generate steam in the range of 175°C to 184°C. This intervention resulted in annual electricity savings of 5 GWh, a 30% reduction in energy costs, and additional secondary savings of USD 33,000 per annum. Most importantly, the shift led to a 66% reduction in CO_2 emissions and was able to meet 95% of the facility's steam demand, demonstrating the significant potential of heat pump technologies in industrial low-carbon transition.

Table 2.5: Schemes facilitating electrification of industrial processes

Policy / Scheme	Applicability	Administering Body	Details
Credit Linked Capital Subsidy and Technology Upgradation Scheme (CLCS-TUS) (MoMSME, 2023)	Small and medium industries in high energy-use sectors	MoMSME, BEE	Supports modernisation of technologies in SMEs for improved energy performance.
Custom Industrial Pilots (e.g., UNIDO-BEE MSME demo projects)	Sector-specific (foundries, ceramics)	MoMSME, BEE, UNIDO	Demonstrated the feasibility of electric heating and drying systems, but not scaled via policy yet.

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[9] Industrial Heat Pumps: It's time to go electric

2.3.3 Low-Carbon Electricity Production

Indian industries remain heavily reliant on grid electricity, which is primarily coal-powered. MSMEs in textiles, plastics, rubber, and food processing source 70–85% of their electricity from the grid, while larger sectors like cement, aluminium, and steel rely more on captive power (see Figure 2.31). In 2022, India's grid emission intensity stood at approximately 715 gCO_2/kWh, significantly higher than countries like France (~27 gCO_2/kWh) (CEA, 2023; Nowtricity, 2024).

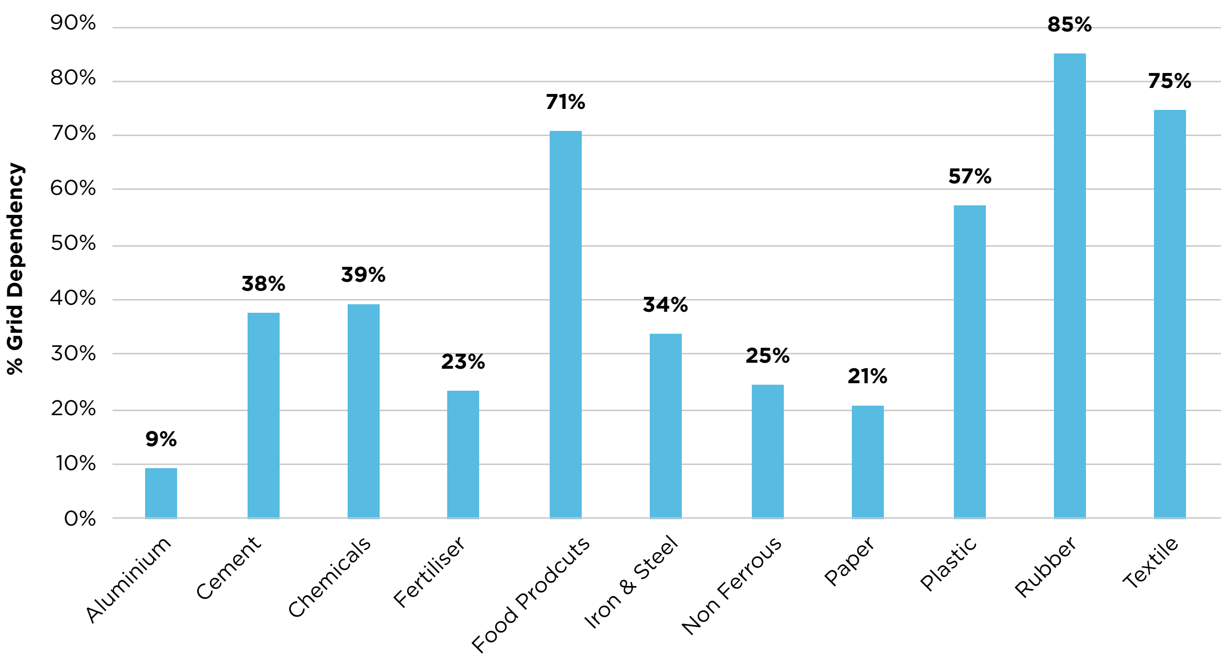

Figure 2.31: Grid dependence across key industrial sectors (2022–23)

Source: *(CEA, 2024)*

India is expanding its clean electricity capacity, reaching around 267 GW of non-fossil based (utility) as of Dec. 2025 (CEA, 2025). Industrial (non-utility) renewable installations reached 8,974 MW, dominated by solar (3,610 MW, 40%) and wind (4824 MW, 53.75%) by 2023-24 (CEA, 2025). Biomass contributes just 265.9 MW, though it is more widely used indirectly via steam and waste heat recovery in sectors like sugar and paper (Table 2.5).

While solar and wind remain the most scalable solutions, their expanded adoption, especially through captive generation, is gradually reshaping industrial electricity use.

India is also beginning to position nuclear power, particularly Small Modular Reactors (SMRs), as a future option for low-carbon captive supply to energy-intensive industries. Recent announcements under the Nuclear Energy Mission for Viksit Bharat envisage indigenously designed SMRs such as the 200 MWe Bharat Small Modular Reactor and a 55 MWe SMR that can be deployed close to industrial loads or at repurposed coal plant sites, with NPCIL inviting private industry participation for captive Bharat Small Reactors to serve sectors like steel, aluminium and chemicals (PIB, 2025). The SHANTI Act, 2025, which opens nuclear generation to greater private and joint-venture participation and explicitly promotes SMRs for industrial and captive use, can enable commercial nuclear solutions to complement renewable energy in decarbonising industrial electricity demand over the medium to long-term (PIB, 2025).

Table 2.6: Renewable electricity usage by industry (2022–23) (BEE, 2022-23)

Industry	RE Generation (GWh)	Energy Consumption (GWh)	% RE of Total Consumption
Rubber	4	2214	0.18
Textile	66	16681	0.4
Food Products	16	3823	0.42
Plastic	7	1199	0.58
Aluminium	584	52967	1.1
Non Ferrous	61	5284	1.15
Chemicals	211	18364	1.15
Paper	175	8320	2.1
Cement	785	30103	2.61
Iron & Steel	2195	77940	2.82

Table 2.7: Policies enabling procurement and use of low-carbon electricity

Policy/Scheme/ Programme	Applicability	Administering Body	Details
Renewable Purchase Obligation (RPO) (MoP, 2022)	Obligated entities, including large industries with open access consumption	MNRE, MoP, CERC, SERCs	Mandates minimum RE procurement targets; updated to include green hydrogen and green ammonia obligations.
Green Energy Open Access Rules **(MoP, 2022)**	Industries with contracted demand >=100 kW to procure RE directly	MNRE, MoP, CERC, NLDC	Simplifies RE procurement and banking; ensures faster approval and concessional charges for industrial users.
Green Term Ahead Market (GTAM) (MNRE, 2020)	Industries participating in power exchange for short-term RE procurement	CERC, IEX	Enables industries to buy RE (solar, wind) on a short-term basis through IEX without a long-term PPA.
ISTS Waiver for RE Projects (MoP 2023)	RE generators supplying to industrial users via open access	MNRE, CEA	Waives interstate transmission charges for solar and wind power until June 2025 for open access projects.

2.3.4 Alternative Fuels

India's energy landscape is dominated by fossil fuels and significant imports. In 2023–24, 89% of crude oil and 47% of natural gas were imported. Coal consumption reached 1,277 million tonnes, of which 20% was imported, with steel alone consuming 58 million tonnes. (BEE 2024)

India is now prioritising alternative, low-emission fuels such as biofuels, cleaner fossil fuels

(CFFs), and electrofuels (E-fuels). Globally, low-emission fuels accounted for just 1% of final energy use in 2022.

Table 2.8: Types of low-carbon fuels

Category	Definition	Examples
Biofuels	Fuels produced from biological/organic materials	Ethanol, biodiesel, bio-oils, bio-alcohols (methanol, butanol)
Cleaner Fossil Fuels (CFFs)	Fossil-based fuels with relatively lower lifecycle emissions	LPG, LNG, RDF-based fuels, crude oil-based fuels with carbon capture
E-fuels	A broad set of technologies that convert non-fossil electricity into fuels, chemicals, or power (Power to X)	Green hydrogen, green ammonia, e-methanol, synthetic methane, e-diesel

Source: *India Energy Scenario 2023-24, MoP; Fuels Industry UK (BEE, 2024)*

Biofuels

Adoption is strong among MSMEs with access to in-house feedstock. For example, paper and pulp units use black liquor and wood residue, and sugar mills leverage bagasse cogeneration, supporting both in-house energy and national ethanol blending targets (20% blending by 2025–26). Agricultural residue use is rising in food processing and textiles, though biofuel adoption remains limited in hard-to-abate sectors (MNRE 2013; Gosavi & Katti, 2016; Nagar & Kumar, 2024).

Box-8: Biofuels in India

According to Energy Statistics of India 2025, as of March 31, 2024, Biomass, which includes agricultural waste, forest residues, and other organic matter, has a potential of 28,447 MW of energy generation, accounting for 1% of the total renewable power potential.

Cogeneration from Bagasse: India has a specific potential of 13,818 MW (1%) from bagasse-based cogeneration in sugar mills. This is a highly efficient form of energy generation, especially in regions with a robust sugar industry.

Cleaner Fossil Fuels (CFFs)

India's gas pipeline network spans 24,720 km, and another 8,600 km is under construction. Industrial natural gas use more than doubled from 701 Million Metric Standard Cubic Meters (MMSCM) in FY 2019–20 to 1,457 MMSCM in FY 2023–24. Refuse-Derived Fuel (RDF) from municipal solid waste, currently underutilised, is primarily consumed by the cement sector, replacing 10–15% of conventional fuels. Only 2,000–3,000 tonnes of RDF are produced daily across 30+ plants. Scaling RDF infrastructure is critical to reducing landfill waste and increasing industrial substitution (Swamy & Arora, 2024).

E-fuels:

Green hydrogen is the leading E-fuel, with growing use in the steel and fertiliser sectors. While cost remains a barrier, projects and pilots across India are gaining momentum. Hydrogen blending in natural gas and its use in industrial boilers are also being explored. A supporting ecosystem is emerging through policy signals and pilot projects to scale up production and reduce costs (NITI Aayog & RMI 2022).

Table 2.9: Green hydrogen projects, (MNRE, 2023)

Project Name	Status	Location	End Use	Electrolyser Capacity (MW)	Project Capacity (Tonnes H_2 P.A.)
OIL India - Jorhat Pump Station AEM Electrolyser	Commissioned	Assam	Blending with Natural Gas	0.1	3
NTPC - City Gas at NTPC Kawas	Commissioned	Gujarat – Surat	Blending with Natural Gas	0.05	0.7
ACME - Green Hydrogen and Green Ammonia Plant, Rajasthan	Commissioned	Rajasthan - Bikaner	Fertilisers	2.1	314
NTPC - Green Hydrogen for Ladakh Fuelling Station	Commissioned	Ladakh - Jammu and Kashmir	Mobility	0.206	29
Hygenco Heartland Ujjain Hydrogen Plan	Commissioned	Madhya Pradesh - Ujjain - Makone	Research	0	0
Shell - Bengaluru Green Hydrogen Project	Commissioned	Karnataka - Bangalore	Green Hydrogen	1	142
L&T - Green Hydrogen Plant	Commissioned	Gujarat – Hazira	Heavy Industry	1	157
GAIL- GH_2 Project	Commissioned	Vijaipur Complex, Madhya Pradesh	PEM electrolyser for the GH_2 producing unit	10	1570

Project Name	Status	Location	End Use	Electrolyser Capacity (MW)	Project Capacity (Tonnes H_2 P.A.)
SJVN Limited -NJHPS Multi-purpose GH_2 Pilot Project	Commissioned	Jhakri, Himachal Pradesh	Green Hydrogen generation	0.1	4

Table 2.10: Government initiatives promoting low-carbon and alternative fuels

Policy/Scheme/ Programme	Applicability	Administering Body	Details
National Green Hydrogen Mission (MNRE 2023a)	Steel, fertilisers, refining, and chemical industries with high hydrogen use	MNRE, MoPNG, MoF	Incentivises green hydrogen production and use in industrial processes; targets 5 Mt by 2030.
MSW to Refuse Derived Fuel (RDF) Policy (Solid Waste Management Rules, 2016)(MNRE 2023b)	Cement, pulp & paper, and other industries using RDF for co-processing	MoHUA, MoEFCC	Mandates urban local bodies to channel RDF from municipal waste to eligible industries for co-processing.
National Policy on Biofuels (2018, amended, 2022) (MoPNG, 2022)	Distilleries, sugar, paper, textile industries using bio-oil, biochar, or 2G ethanol	MoPNG, MNRE	Supports industrial biofuel applications, including 2G ethanol, biodiesel, biochar, and other renewable fuels.
Bio-Energy Programme (Waste to Energy Sub-scheme) (MNRE 2022)	Industries using RDF, biomass pellets, or bio-CNG for thermal substitution	MNRE	Provides financial support for industrial adoption of waste-derived fuels and related infrastructure.
Gujarat Green Hydrogen Policy 2024 (GEDA, 2024)	Industries in Gujarat are piloting green hydrogen-based process fuel switching.	Govt. of Gujarat	Offers capital subsidies and demand aggregation incentives for hydrogen fuel switching in industries.
PM-JI-VAN Scheme (PIB, 2023)	Provides financial support to 2nd-generation biofuel production plants – both commercial and demonstration.	Centre for High Technology (CHT), MoPNG	Financial assistance in the form of viability gap funding is provided – INR 150 crore for commercial projects and INR 15 crore for demonstration projects.

2.3.5 Circular Economy

The circular economy offers potential for emission reductions by lowering demand for virgin materials. Globally, only 7.2% of materials in 2023 were from circular sources (down from 9.1% in 2018). Yet, recycling rates are growing: 90% of steel, 73% of aluminium, 60% of paper, 40% of copper, and 27% of concrete waste is recycled worldwide (Deloitte & Circle Economy Foundation, 2023).

- **Steel:** India's Steel Scrap Recycling and Vehicle Scrapping policies promote circularity, though scrap availability remains a challenge. India imported 9.8 million tonnes of ferrous scrap in 2022–23, 30% of total demand (Kumar & Agarwal, 2024). Scrap-based steelmaking is vital for low-carbon transition and aligns with regulations like the EU's CBAM.

- **Cement:** The sector uses industrial and other waste (e.g., fly ash, slag, gypsum, RDF, biomass). Further progress is needed to reduce clinker use and improve concrete efficiency through strategies like longer building lifespans and construction waste recycling (GCCA & TERI, 2025; Deloitte & Circle Economy Foundation, 2023).
- **Aluminium:** Against a global recycling at 98%, the 30% rate in India is low. The Non-Ferrous Metal Scrap Recycling Framework seeks to formalise scrap processing and expand secondary aluminium production, which requires only 5% of the energy used in primary production, delivering substantial emissions savings (Deloitte & Circle Economy Foundation, 2023).

Box-9: Case Study: Nucor Steel

HNucor Corporation (USA) is a global leader in circular steel production. Nearly 70% of Nucor's steel is produced using Electric Arc Furnace (EAF) technology, which relies mainly on scrap metal and results in 75% lower emissions intensity compared to traditional blast furnace routes.

Key Achievements:

- Over 20 million tonnes of scrap recycled annually.
- GHG intensity of 0.45 tCO_2/tonne of steel, compared to the global average of ~1.85 tCO_2/tonne.
- Achieved Scope 1 & 2 emissions that were 67% below the global steelmaking average.
- Committed to Net Zero by 2050, with interim targets set for 2030.

Table 2.11: Circular economy policies for resource recovery and industrial recycling

Policy/Scheme/ Programme	Applicability	Administering Body	Details
Steel Scrap Recycling Policy (MoS, 2019)	Steel sector using scrap-based production (EAF/IF route)	Ministry of Steel	Promotes the use of steel scrap for greener production routes, reducing demand for virgin ore and energy use.
CPCB Co-processing Guidelines for Waste in Cement Kilns (CPCB, 2017)	Cement and thermal process industries co-processing RDF, plastic, and industrial waste	CPCB, MoEFCC	Allows safe and regulated industrial waste co-processing in cement kilns; reduces reliance on virgin fuels.
Vehicle Scrappage Policy, (2021) (MoRTH 2021)	Steel, aluminium, and auto sectors through formal scrap recovery	MoRTH, MoHI	Facilitates recovery of end-of-life vehicles and materials like steel, aluminium, and plastics for secondary use.

Policy/Scheme/ Programme	Applicability	Administering Body	Details
Draft National Resource Efficiency Policy (NREP) (MoEFCC, 2019)	Cross-sectoral push for secondary resource use in industrial supply chains	MoEFCC	Outlines targets for material efficiency, reuse, and recycling in industrial value chains; yet to be finalised.
Extended Producer Responsibility (EPR) (ORF, 2025)	Holds producers responsible for the disposal and handling of products post-consumption.	MoEFCC, CPCB	Mainly responsible for reducing packaging waste, this policy has been aimed at single-use plastics. However, the same has been extended to e-waste as well.

2.3.6 Carbon Capture, Utilisation, and Storage

Carbon Capture, Utilisation, and Storage (CCUS) is emerging as a key pillar of India's industrial sector low-carbon transition strategy, particularly for hard-to-abate sectors such as steel, cement, refinery and chemicals. A dedicated "Carbon Capture, Utilisation, and Storage (CCUS) Policy Framework and its Deployment Mechanism in India" released by NITI Aayog positions CCUS as critical for enabling low-carbon industrial growth, while recognising the cost and regulatory challenges associated with early deployment (NITI Aayog, 2022).

India is beginning to build a CCUS ecosystem through pilot and demonstration projects, academia-industry testbeds, and new policy instruments. Initial efforts include cluster-based CCU testbeds in the cement sector, emerging proposals for CO_2 transport and storage infrastructure, and exploratory work on linking CCUS projects with evolving domestic carbon markets and potential international carbon finance. Though nature-based solutions continue to complement these efforts, industrial low-carbon transition is increasingly anchored in technological measures such as CCUS to deal with process emission.

Global momentum further reinforces this direction. By 2022, there were 30 commercial CCS facilities worldwide, 11 under construction, and 153 in development, with 61 new facilities added to the pipeline in a single year, reflecting the rapid expansion of the project pipeline. The US, supported by strong tax incentives, has emerged as the largest CCUS market, while countries such as Netherlands, Norway and the UK are advancing shared industrial clusters for storage and transport. This offers relevant lessons for India's emerging plans for CCUS hubs linked to major industrial and coastal corridors.

Table 2.12: CCUS projects and initiatives in India

Industry	Company	Details of the project
Steel	Tata Steel	Tata Steel commissioned a 5 tpd CO_2 capture plant from the blast furnace at the TSL Jamshedpur site, with upcoming plans to re-use the captured CO_2 within the process value chain.
	JSPL	JSPL commissioned a 2000 tpd CO_2 capture plant from the coal gasification operations at Angul, with plans for CO_2 utilisation into bio-ethanol, methanol, and soda ash, etc.

Industry	Company	Details of the project
Cement	Dalmia Cement	Dalmia Cement signed an MOU with a carbon capture technology provider at their Tamil Nadu plant to capture 500,000 TPA CO_2.
Chemical	BHEL and CSIR-CIMFR	Coal-to-methanol pilot plants commissioned for carbon capture and their utilisation in methanol production
	Tuticorin Alkali and Chemicals (TFL)	TFL commissioned a 200 tpd CO_2 capture plant, and captured CO_2 is utilised in baking soda production
Petrochem	BPCL	BPCL conducted a feasibility study for the gasification of 1.2 Mtpa petcoke and utilised it in carbon-abated materials, the power sector, etc.
Oil and Gas	ONGC	ONGC signed an MoU with Shell for a study exploring a storage site for capturing carbon and EOR in key basins in India, and another MoU with Equinor for evolving hubs and projects related to CCUS.
	ONGC and IOCL	Conducted a feasibility study for 0.7 Mtpa of captured CO_2 from IOCL's Koyali refinery and utilising the captured CO_2 for Enhanced Oil Recovery at Gandhar oilfields of ONGC, and usage in the F&B sector
Power	NTPC	Pilot project at Vindhyachal thermal power plant and a plan to convert captured carbon into methanol.
		Development of amine-based technology for CO_2 emissions capture.
		Demonstration of biotechnology-based (microalgae) CO_2 emissions capture.
		Pilot plant on CO_2 utilisation (10 TPD CO_2) for the generation of an ethanol plant at NTPC power plant premises.
		Pilot project on CO_2 utilisation for the production of carbonated aggregates by means of fly ash, and to capture CO_2 from the flue gas of a power plant.

Source: Perspectives on CCUS deployment on a large scale in India: Insights for low carbon pathways

(NITI Aayog, 2022)

2.3.7 Carbon Management

India's carbon management framework operates across two complementary levels: domestically through instruments such as the Carbon Credit Trading Scheme (CCTS) and the MISHTI initiative, which address industrial compliance and nature-based offsetting, respectively and internationally through participation in Article 6.4 of the Paris Agreement, which enables cross-border mitigation and carbon credit trading. Together, these mechanisms establish a layered approach to industrial low-carbon transition, allowing energy-intensive sectors such as steel and cement to achieve emission reductions via verified low-carbon options.

Table 2.13: Carbon management and trading mechanisms for industrial emission reduction

Policy/Scheme/ Programme	Applicability	Administering Body	Details
Carbon Credit Trading Scheme (CCTS) (BEE 2023)	Industries adopting low-carbon fuels, energy efficiency, or CCS are eligible for trading credits.	MoEFCC, BEE	Operational national compliance carbon market for verified industrial emission reductions, governed under the Energy Conservation Act.
Mangrove Initiative for Shoreline Habitats & Tangible Incomes (MISHTI) (MoEFCC, 2024)	Industries interested in carbon offsets through nature-based solutions (e.g., coastal cement plants)	MoEFCC	Promotes afforestation and carbon sink generation in coastal regions, applicable for offsetting industrial residual emissions.
Article 6.4 Paris Agreement Participation	Industrial projects in GHG mitigation, alternative materials, and removal activities	MoEFCC (National Designated Authority)	Enables trading of Internationally Transferred Mitigation Outcomes (ITMOs); key notified technologies include renewable energy with storage, green hydrogen, compressed biogas, CCUS, green ammonia, sustainable aviation fuel, and emerging energy efficiency technologies.

Ministry of Steel's Green Steel Taxonomy **(Dec, 2024)**	Adoption of the Green Steel Taxonomy is not mandatory. Steel producers may opt in to get their steel assessed and certified as "green".	Ministry of Steel (MoS)	India is the first country to notify a Green Steel Taxonomy supporting global competitiveness. "Green Steel" shall be defined in terms of percentage greenness of the steel, which is produced from the steel plant with CO_2 equivalent emission intensity less than 2.2 tonnes of CO_2e per tonne of finished steel (tfs). The greenness of the steel shall be expressed as a percentage, based on how much the steel plant's emission intensity is lower compared to the 2.2 tCO_2e/tfs threshold.

Conclusion

India's industrial sector stands at the core of its development strategy, contributing substantially to GDP, employment, and export competitiveness, even as the country moves toward a low-carbon growth model. Balancing rapid industrial expansion with climate mitigation is therefore essential, particularly in hard-to-abate sectors.

Over the past decade, India has built a robust policy foundation for industrial low-carbon transition through schemes such as Perform, Achieve, and Trade (PAT), the recently notified Carbon Credit and Trading Scheme (CCTS), and sector-specific programmes that promote energy efficiency, electrification, fuel switching and circularity. These instruments reflect an approach that is responsive to domestic development needs rather than simply mirroring global templates.

Achieving a competitive low-carbon transition, however, will require scaling these efforts through stronger coordination, deeper markets and accelerated technology deployment. Priority actions include: tightening and expanding performance-based schemes, setting clear and credible low-carbon standards for major industrial value chains and designing targeted financial instruments and de-risking mechanisms, especially for MSMEs, to unlock investment in efficiency, clean electricity, CCUS and clean fuels. An integrated approach that links policy, regulations, financial incentives, and innovations can position India not only to meet its Net Zero goals but also to emerge as a global leader in competitive low-carbon industrial development.

3

INDUSTRY SECTOR MODELLING AND RESULTS

Industry Sector Modelling and Results

3

This chapter presents the modelling outcomes that explore how India's industry sector may evolve under two scenarios: the Current Policy Scenario (CPS) and a Net Zero Scenario (NZS) aligned with India's 2070 climate commitment. The results trace changes in commodity demand, efficiency improvements, technology and fuel mix to 2070, while also examining the investment requirements needed to enable this transition.

For estimation of industrial energy-use, emissions and investment, the model disaggregates industry into nine sectors: i) Steel, ii) Cement, iii) Aluminium, iv) Textiles, v) Paper and Pulp, vi) Ethylene, vii) Chlor-Alkali, viii) Fertiliser and ix) Refineries. Together, these sectors account for 51% of industrial energy demand and ~60% of industrial emissions in 2025. Other sectors, such as Glass, Bricks, Ceramics, Rubber, Food processing, etc., are not modelled separately due to limitations in baseline data availability; instead, they are represented as a single aggregated "other industry" category. Future iterations of this modelling exercise will seek to further disaggregate this category as data quality and coverage improve.

The next section discusses the sector-wise approach and methodology adopted, including the results, followed by overall total industrial sector emissions, mitigation strategies and investment requirements.

3.1 MODELLING FRAMEWORK

For the industry sector, transition pathways are developed utilising an integrated energy system modelling framework that comprises all major energy-economy sectors and represents their interlinkage. One of the key inputs to this framework is activity demand for each end-use sector; in the case of industry, this is the projected production of individual subsectors. Production trajectories are generated exogenously using a combination of methods, including historical trend analysis, econometric regression, elasticity analysis and per capita saturation trends in major economies. Detailed production projections for each industry subsector are presented in the respective subsector sections. Given these activity projections, the model uses the defined technology options with their techno-economic parameters and the assumed fuel mix, including domestic availability, import and price trajectories. The model then determines the evolution of capacity and fuel use required to meet sub-sectoral production under two scenarios: Current Policy Scenario (CPS) and Net Zero Scenario (NZS) discussed in the next sections. These scenario-specific assumptions on technology choice and fuel mix finally determine the estimates of industrial energy demand, emissions, and investment requirements (see Figure 3.1).

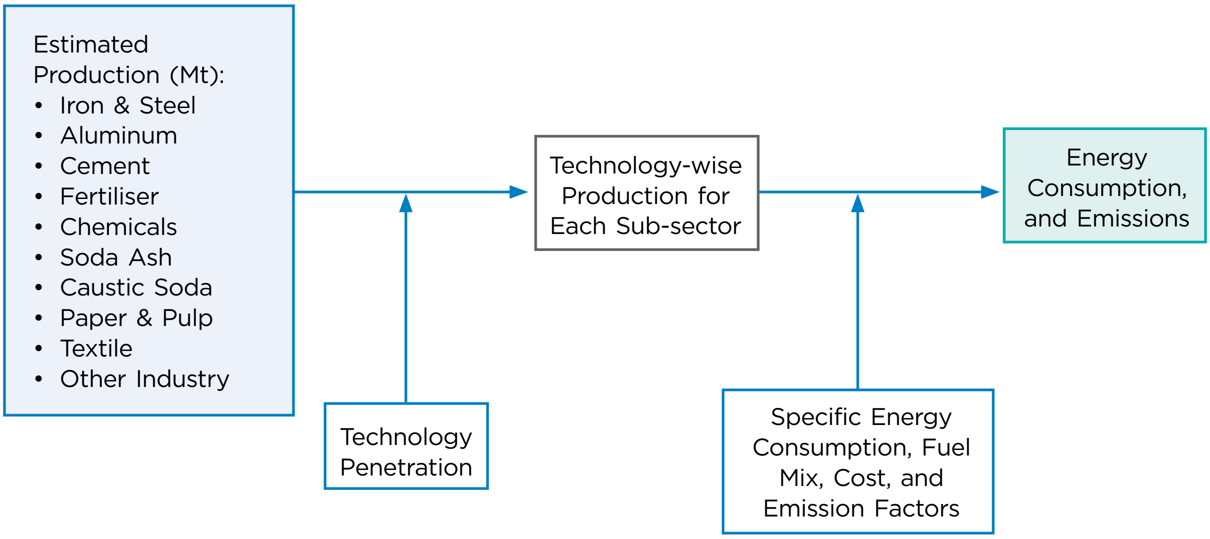

Figure 3.1: Modelling framework

Demand Estimation

Annual production is projected using two complementary approaches selected to reflect underlying production dynamics in each industry based on changes in per-capita GDP (See Annexure-I for Real GDP growth rates and population projections).

- A saturation-growth (logistic S-curve) is used for stock-building materials — steel, cement, aluminium, and textiles – in which per-capita use rises with development and then plateaus. Per-capita demand is modelled as:

$$ln\frac{S}{(So-S)} = a * ln\left(\frac{GDP}{Capita}\right) + b$$

Where:

S = per capita industrial demand
So = saturation limit
a,b = coefficients estimated from historical data

Saturation limits are calibrated to global benchmarks and India's long-run stock needs for housing, infrastructure, and capital goods.

A regression-based model is applied where demand follows measurable drivers rather than stock saturation, as in the case of fertilisers, chemicals (ethylene), chlor-alkali (soda ash, caustic soda), paper and pulp, and "other industry." A simple per-capita specification used in this report is:

$$S = m * \left(\frac{GDP}{Capita}\right) + c$$

Where:

S = per capita industrial demand
m, c = coefficients estimated on historical data

Energy and Emission Estimation

Each sub-sector is then mapped to its prevailing technology pathways, associated specific energy consumption, and fuel consumption patterns. This includes categorisation into thermal and electrical energy demands (further divided into grid and captive), and identification of primary fuels such as coal, natural gas, electricity, and renewable sources. Energy demand is calculated by multiplying the estimated production volumes by technology-specific Specific Energy Consumption (SEC) in Gigajoules (GJ) or Tonnes of Oil Equivalent (toe) per tonne.

Further, industry sector emissions are estimated using IPCC Tier 2 or Tier 3 methodologies and are attributed to a combination of sources, including:

1. **Energy Emissions**
    a. **Fuel-Related Emissions:** Emissions resulting from the combustion and utilisation of fuels (both fossil and non-fossil sources) at industrial facilities for applications other than electricity generation, such as for producing process heat or steam.
    b. **Electricity Generation Emissions:** Emissions associated with the production of electricity consumed by industrial facilities, whether the electricity is generated onsite or procured from the grid.
2. **Industrial Processes and Product Use (IPPU) Emissions**

Emissions arising directly from chemical or physical transformations of material in industrial activities and product use, rather than from fuel consumption for energy. Typical examples include the process CO_2 released during clinker production in the cement industry, the reduction reaction in iron and feedstock or process emissions in chemical and fertiliser manufacturing.

The modelling outputs include emissions of CO_2, CH_4, and N_2O, CF4, C2F6, etc., expressed in CO_2e terms using the AR5 method for consistency with national inventory reporting.

Scenarios

The pace and shape of India's industrial sector energy transition will be driven by policy choices, technology deployment rates, and structural shifts in the economy over the coming decades. To reflect this complexity and explore a range of plausible pathways, this study develops two distinct scenarios for the industry sector: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS).

Current Policy Scenario (CPS): The CPS represents a continuation of existing policies and initiatives, reflecting the current pace of technology deployment, regulatory enforcement, and voluntary industry efforts. It assumes gradual improvements in energy efficiency, moderate fuel diversification, and incremental uptake of cleaner technologies within the prevailing policy landscape.

Net Zero Scenario (NZS): The NZS outlines a transformative and more ambitious pathway aligned with India's commitment to reach Net Zero GHG emissions by 2070. It assumes proactive policy interventions, accelerated innovation, and a system-wide shift toward electrification, low-carbon fuels, circular economy principles, and carbon capture technologies. This scenario is shaped by the long-term NZ goal and supported by global best practices.

While carbon capture, utilisation and storage (CCUS) is recognised as a critical enabler for achieving Net Zero in hard-to-abate industrial sectors, CCUS is not embedded as a baseline technology within the sectoral technology mix. Instead, the model estimates the magnitude of carbon capture required to close the residual emissions gap in the Net Zero Scenario, and these requirements are analysed separately and discussed under overall industry results.

The next sections present sub-sectoral modelling results under the Current Policy Scenario (CPS) and Net Zero Scenario (NZS), covering demand projections, technology pathways, energy use, emission intensity, and investment needs, while sectoral landscapes and energy consumption profiles can be referred from Chapter 2.

3.2 RESULTS FOR INDUSTRY SUB-SECTORS

3.2.1 Steel

Projections for Crude Steel Production

Crude steel production is projected using a saturation-growth model as described in Section 3.1, wherein per capita steel consumption rises with income until saturating at a high level. India's low current per-capita steel use underscores the scope for growth in comparison to other economies. For example, at around 97.7 kg/capita in 2023-24, India's steel consumption is one-third of the global average and only ~20% of the level seen in advanced economies (Ministry of Steel, 2025; Climate Policy Initiative, 2023).

As India industrialises, steel demand is expected to increase rapidly by mid-century, after which the growth is expected to slow down. This mirrors the pattern seen in other industrialised nations (See Figure 3.2). Using a logistic S-curve with an assumed saturation around 450 kg/capita (peak levels observed in developed economies), India's total crude steel production is projected to rise from 144.29 Mt in 2024 to 624 Mt by 2050 and 821 Mt by 2070 (see Figure 3.3).

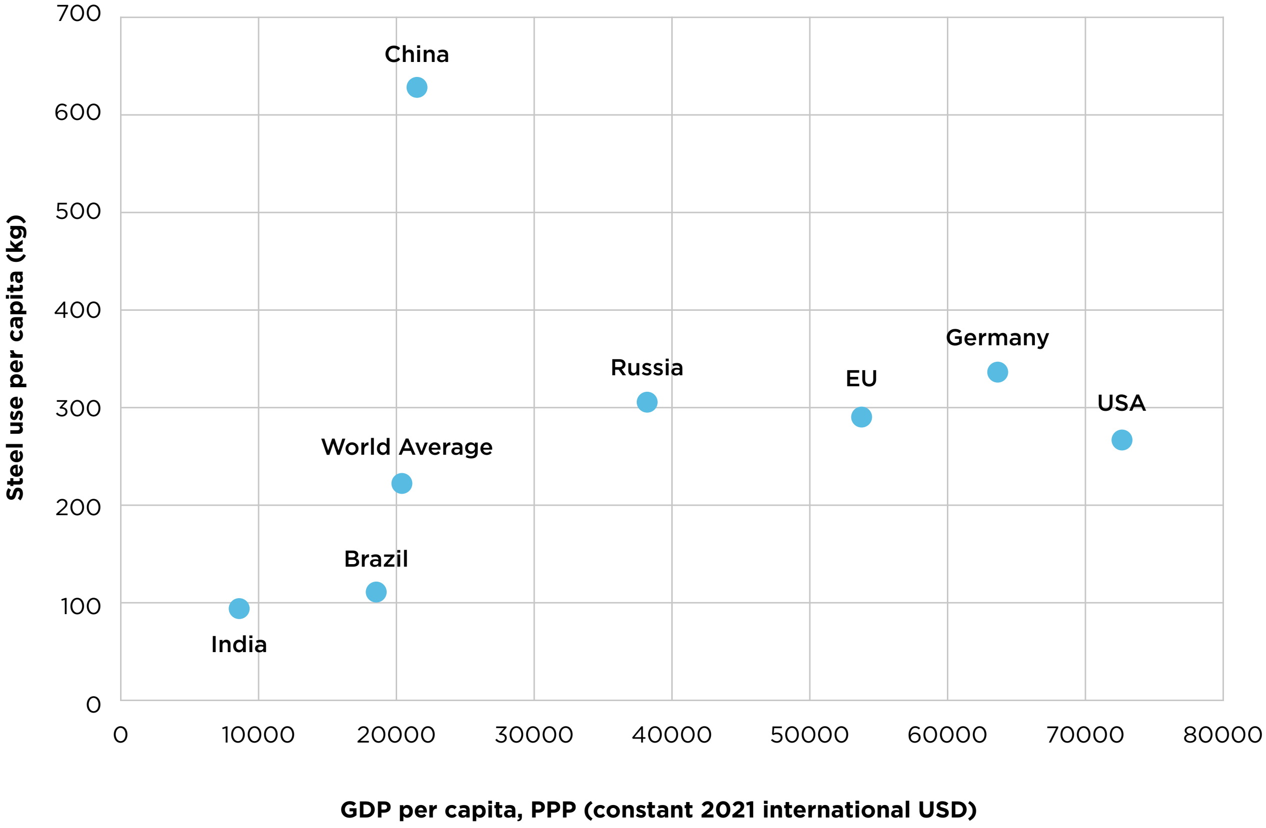

Figure 3.2: Global comparison of GDP/capita vs steel use/capita

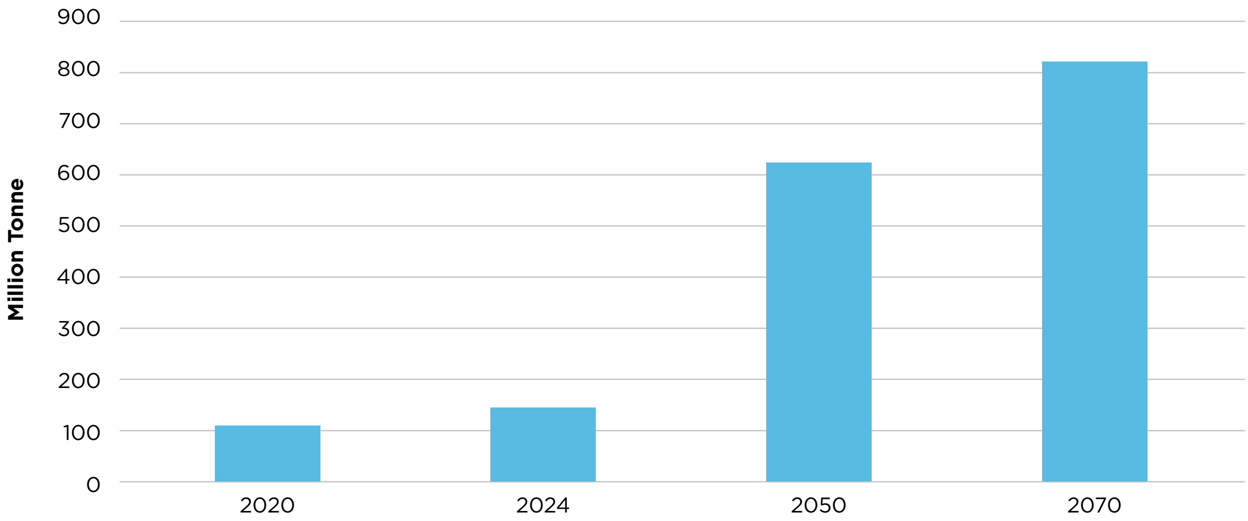

Figure 3.3: Crude steel production (million tonnes)

Scenarios

Two scenarios are developed to assess low-carbon transition pathways for the steel sector: Current Policy Scenario (CPS) and Net Zero Scenario (NZS) (as described in Table 3.1). Both scenarios assume similar growth in steel production but differ fundamentally in their assumptions on technology mix, energy efficiency, fuel use, source of electricity, and scrap utilisation, which are tabulated below:

Table 3.1: Scenario assumptions for steel sector

	Current Policy Scenario	Net Zero Scenario
Technology Mix	• Dominance of Blast Furnace & Basic Oxygen Furnace (BF-BOF) till 2050, beyond which annual capacity addition reduces • DRI (Gas)-EAF to be transition technology • DRI (Hydrogen)-EAF Commercialisation starts from 2035, and scale comes only after 2045 • DRI(Coal-IF): No addition after 2030	• Dominance of Blast Furnace & Basic Oxygen Furnace (BF-BOF) till 2040 and no new addition after 2060; BF-BOF capacity that remains in 2070 is coupled with CCS/CCUS • DRI (Gas)-EAF to be transition technology; No capacity addition after 2040 • DRI (Hydrogen)-EAF commercialisation starts from 2030 with significant scale emerging from the 2040s. • DRI(Coal-IF): No addition after 2030
Specific Energy Consumption (SEC)	Overall, SEC declines by roughly 12% by 2050 and about 23% by 2070 versus 2025, driven by changes wherein average SEC catches up with India's best plants as of today.	Overall, SEC falls by around 24% by 2050 and approximately 35-38% by 2070 relative to 2025, driven by changes wherein average SEC catches up with global best plants as of today.
Share of Grid/Captive	Share of captive: 64% (2025) to 56% (2050) and 50% (2070), reflecting conservative views wherein the industry adds significant fossil capacity to meet the electric needs reliably.	Share of captive: 64% (2025) to 48% (2050) and 35% (2070), reflecting a gradual increase towards the use of Grid, which is assumed to be low-carbon and reliable.
Fuel Mix for Captive Power	Coal-based generation: 93% (2025) to 53% (2050) and 40% (2070), wherein coal continues to be the dominant source owing to reliability concerns.	Coal-based generation: 20% (2050) and phased out by (2070) due to priority shift towards renewables and captive nuclear driven by ambitious targets through CCTS, tightening of taxonomy thresholds and decline in storage costs for deploying RTC renewables.
Scrap Share	Remains the same at the current level of 20% in 2025 as the ecosystem for Circularity improves gradually	Improves from 20% in 2025 to 30% by 2050 and 40% by 2070 with an enabling ecosystem for circularity through strong EPR policies, minimum recycled content norms and a formalised value chain.

Results

Energy Demand: To meet a nearly sixfold increase in steel production, from 144 Mt in 2024 to 820 Mt in 2070, final energy consumption is projected to rise from 69 Mtoe in 2025 to 251 Mtoe in 2070 (3.6x) under Current Policy Scenario (CPS) and to 155 Mtoe under Net Zero Scenario (NZS) (2.2x) (see Figure 3.4). Despite the significant scale-up in production, energy intensity improves even under CPS due to energy efficiency gains, gradual penetration of newer technologies such as Green H_2, and increased use of renewable energy. In the NZS, wider adoption of efficiency measures, higher scrap utilisation, phase-out of energy-intensive processes such as coal-based DRI, and greater use of low-carbon fuels result in final energy demand being about 38% lower than under CPS. Notably, after 2050, NZS shows a flattening of energy demand even as production continues to grow. These trends align with global Net Zero roadmaps (IEA, Mission Possible Partnership), which indicate that steel sector energy use plateaus or declines after mid-century as a result of transformative technological changes.

Technology and Fuel Mix: By 2070, the nature of steel production under the Net Zero Scenario fundamentally differs from the present. The NZ pathway is dominated by low-carbon routes, with approximately 40% of output from scrap-based EAF and around 50% from GH_2 DRI–EAF, leaving only about 10% from coal-based BF–BOF equipped with CCS. In contrast, under Current Policy Scenario (CPS), BF–BOF remains the single largest route, supplying around 50% of production in 2070, with hydrogen DRI–EAF (25%), NG DRI–EAF (7%), and scrap-based EAF (18%) comprising the balance. The divergence in technology pathways is already evident in 2050, when Net Zero Scenario shows a pronounced shift towards hydrogen DRI–EAF and higher scrap shares, while Current Policy Scenario (CPS) continues to be reliant on BF-BOF capacity.

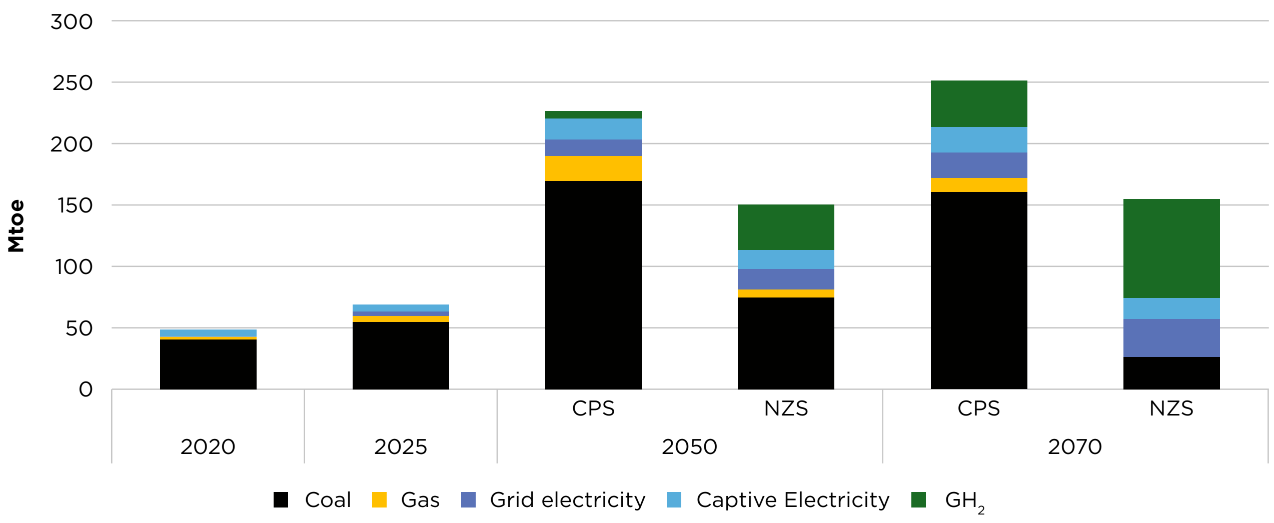

Figure 3.4: Final energy consumption in steel sector (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

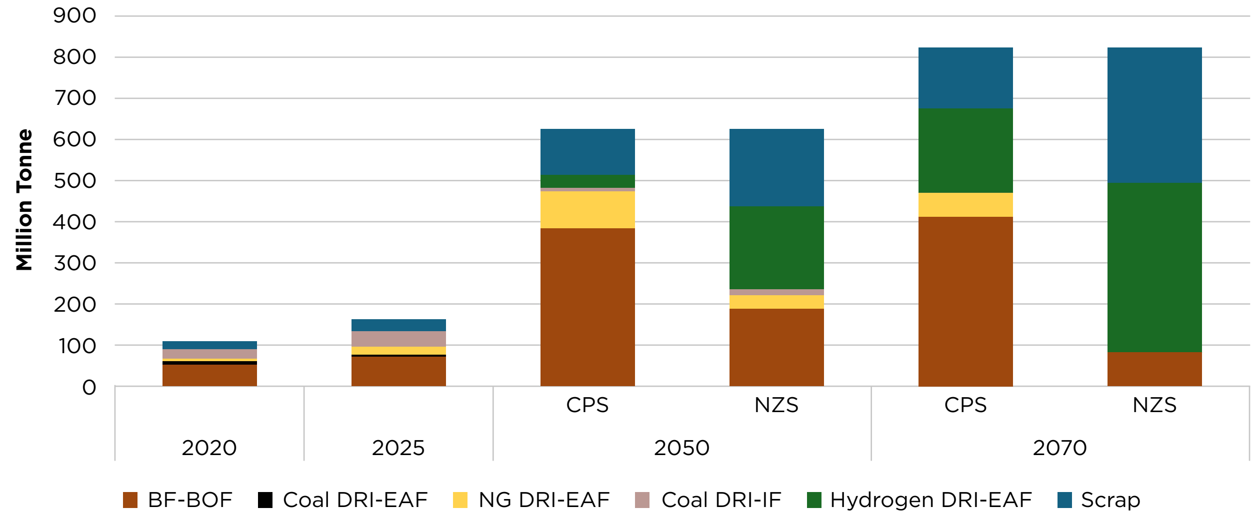

Figure 3.5: Technology-wise steel production (million tonnes) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

This shift in technology mix directly drives the transformation of the fuel profile (see Figure 3.5). The evolution of fuel mix under the Current Policy Scenario reflects a continuation of the coal-centric production pathway. The combined use of coking and non-coking coal (excluding non-coking coal used for electricity generation) under this scenario rises from 55 Mtoe in 2025 to ~160 Mtoe by 2070, supplying most of the sector's energy. Electricity also sees growth from 9 Mtoe in 2025 to ~41 Mtoe by 2070, with a high EAF share; however, captive electricity is largely from the coal route. Under Net Zero Scenario, total coal use falls sharply to 26 Mtoe by 2070, confined mainly to residual BF-BOF capacity equipped with CCS. Green hydrogen becomes a core energy carrier, reaching 81 Mtoe (over 50% of final energy). In parallel, captive clean electricity from renewables and nuclear expands to about 17 Mtoe. By 2070, Net Zero Scenario is dominated by hydrogen and low-carbon captive power, with fossil fuels playing only a residual role broadly consistent with IEA Net Zero 2050 and Mission Possible Partnership pathways, which envisage roughly half of steel energy from hydrogen and a steep reduction in coal use.

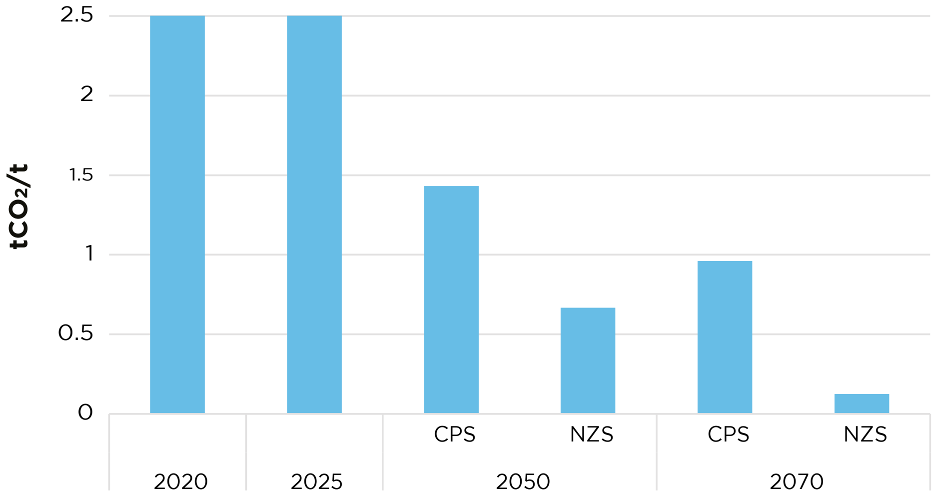

Figure 3.6: Emission intensity of steel sector (tCO_2/t) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Emission Intensity: Emission intensity in both scenarios declines over time (Figure 3.6), but the depth of reduction differs markedly, with the Net Zero Scenario reflecting an ambitious decline compared to Current Policy Scenario (CPS). In CPS, emission intensity reduces by 44% in 2050 and 62% by 2070 over 2.54 tonnes CO_2/tonne of crude steel in 2025. However, in Net Zero Scenario, emission intensity declines by 74% by 2050 and 95% by 2070, driven by a shift towards low-carbon sources.

These outcomes illustrate how technology and fuel shifts translate into a deep reduction in emissions intensity, and underscore the need for strong policy, investment, and infrastructure support. The key barriers and enablers shaping this transition are outlined below.

Barriers and Enablers for Steel Sector Energy Transition

Challenges

a. **Low-grade iron ores:** Of India's 24,058 Mt of hematite reserves, only 12% is high-grade, 31% low-grade, and the rest medium (Ministry of Steel, 2024). Heavy reliance on low-grade ore generates more slimes and fines, cutting plant efficiency and raising emissions, while mining and crushing also cause iron losses.

b. **Heavy reliance on BF-BOF:** Current steel production depends heavily on the BF-BOF route, which accounted for 44% of the crude steel production in 2021-22, compared to 30% globally (IEA, 2020). Producing steel through this route is heavily coal-dependent and carbon-intensive, with the Indian average at 2.36 tCO_2/tcs, while globally, it ranges between 1.85 and 1.91 tCO_2/tcs. (Elango et al, 2023) (Ministry of Steel, 2024).

c. **High cost of new technologies:** 100% hydrogen DRI-EAF has yet to be cost-competitive at current hydrogen prices. Global studies show that hydrogen-based DRI plants require around 30-40% higher capital investment cost and 15-25% higher operating costs, assuming current green hydrogen prices (Eureka 2025).

d. **CCUS technologies:** embedded within the steel units can reduce 56% of the BF-BOF emissions but cost between 45-60 USD/tCO_2 (Ministry of Steel, 2024). Moreover, for CCUS technologies to succeed in India, pipeline networks and storage infrastructure need to be built up. In 2025, Indian steel emits about 2.1 tCO_2/tcs (estimated), higher than among global peers, leaving Indian steel vulnerable to CBAM kind of policies.

e. **Availability of raw materials:** Around 30 Mt of scrap was produced in 2020-21, well below the requirement (PIB, 2023). Decarbonising steel will need to ensure a high scrap mix in overall steel production.

f. **Lack of global steel taxonomy:** While India is the first to have a green steel taxonomy in place, global standards will help harmonise emissions per tcs and increase demand globally for low carbon steel (PIB, 2024)

g. **Lack of willingness to pay green premium for steel:** India's price-sensitive market shows limited readiness to pay more for low-carbon or "green" steel. This weak demand signal discourages producers from making large investments in low-carbon technologies and capacity upgrades

Suggestions

a. **Scale up Electric Arc Furnace (EAF) route with a dedicated scrap policy:** Scaling up EAF will require a dedicated and robust framework for Scrap Policy that goes beyond vehicle scrappage policy and includes segregation networks, formal scrap collection targets, digital information of the scraps used, and a certification mechanism for quality assurance.

b. **Thermal Energy Management:** Deepen specific thermal energy consumption targets under CCTS, to promote adoption of technologies such as Coke Dry Quenching (CDQ) & Top Gas Recovery Turbines (TRT) to recover pressure/heat

c. **Blending hydrogen in BF-BOF:** The transition plan should be to blend hydrogen in BF-BOF plants through retrofitting in existing plants. In 2023, Tata Steel set up a trial project to inject 40% hydrogen gas in the ‘E’ Blast Furnace in Jamshedpur, with the potential to reduce 7-10% CO_2 per tonne of steel (Tata Steel, 2023).

d. **Green route:** GH_2-DRI EAF route is the long-term solution to decarbonise the steel industry. To improve the cost competitiveness of steel from this route, the National Green Hydrogen Mission should bring in mechanisms to move from pilots to commercial-scale projects leveraging blended financial structures.

e. **Better use of low-grade iron ore:** Beneficiation process needs to be promoted as the efficient technology route for better utilisation of low-grade ore, especially by Integrated Steel Plants (ISPs).

f. **Incentivise green public procurement:** The government should deploy Green Public Procurement (GPP) to create early domestic demand for low-carbon steel in infrastructure projects.

g. **Harmonisation of Indian Steel Taxonomy:** Aligning Indian definitions of “green steel” with international taxonomies will safeguard competitiveness in global markets.

3.2.2 Cement

Projections for Cement Production

Cement production in India is projected using a logistic saturation model linked to economic growth, following the methodology outlined in Section 3.1. Historically, per-capita cement consumption in developed economies rose steeply during early phases of rapid infrastructure and housing expansion, and gradually plateaued as economies matured. India is currently in this accelerated growth phase of the S-curve. Figure 3.7 correlates per-capita cement consumption with per-capita GDP, benchmarked against the experience of other large industrialising economies.

Using this approach, India’s total cement production is projected to increase sharply through mid-century before stabilising. Cement production is projected to increase from 451 Mt in 2025 to 1,590 Mt by 2050, and then gradually level off around 1,985 Mt by 2070 (see Figure 3.7). This represents more than a threefold increase by 2050, driven by sustained demand from housing, urban infrastructure, industrial corridors, transport networks, and supported by major national programs such as Pradhan Mantri Awas Yojana (Housing for All), Smart Cities Mission, Bharatmala and Sagarmala. The demand slightly tapers in the later period, with a 4.5x increase by 2070 over 2025 levels.

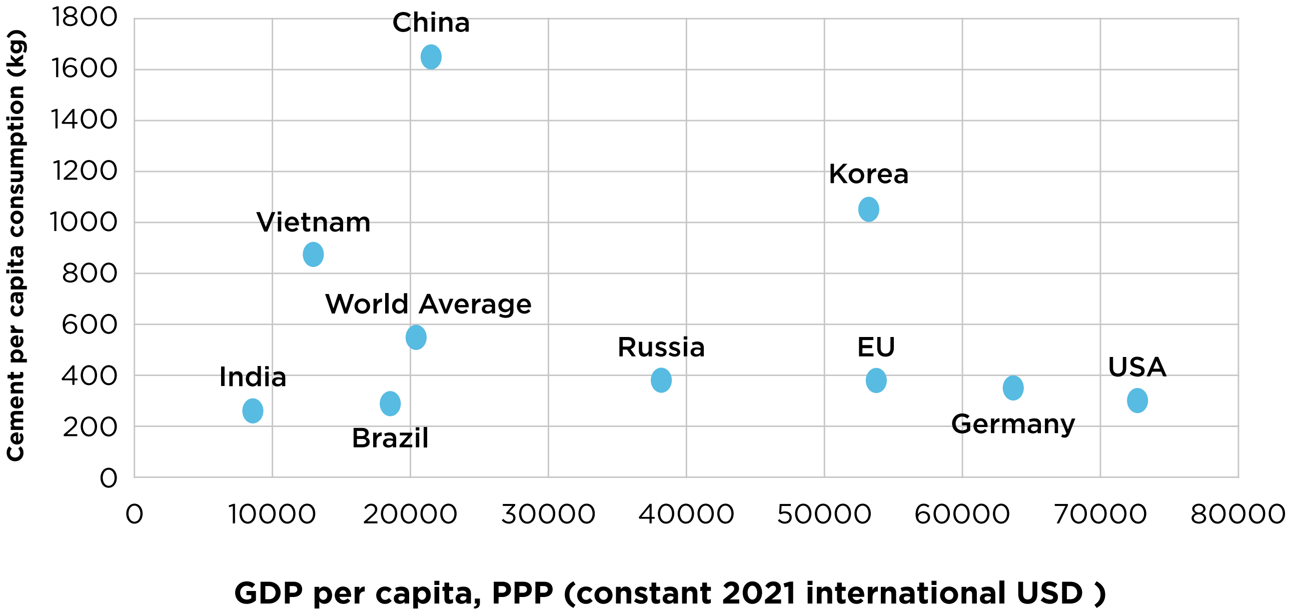

Figure 3.7: Global comparison of GDP/capita vs cement use/capita

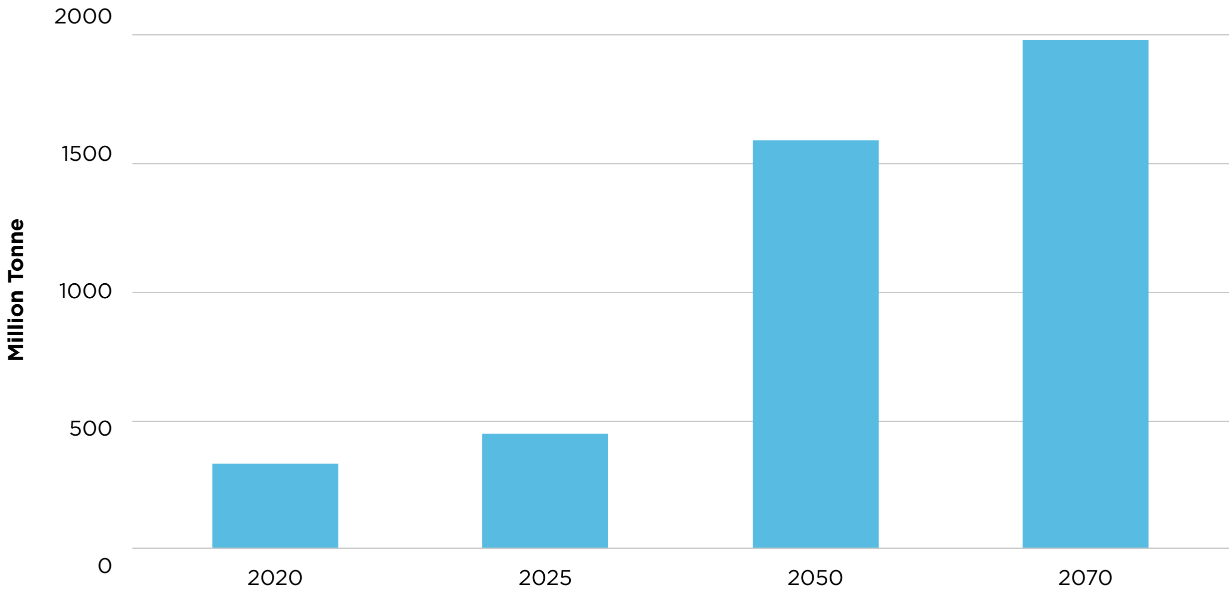

Figure 3.8: Cement production (million tonnes)

Scenarios

Two scenarios are examined for the cement sector: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS), which diverge mainly in the degree of technology adoption and emission-mitigation ambition (See Table below)

Table 3.2: Scenario assumptions for cement sector

	Current Policy Scenario	Net Zero Scenario
Clinker Ratio	Average clinker-to-cement ratio declines moderately from about 0.67 in 2024 to 0.6 by 2070, reflecting gradual improvements and no additional new binder chemistries.	Average clinker-to-cement ratio falls to 0.55 by 2070, global best. This scenario envisages large-scale deployment of low-clinker binders such as LC3 (limestone calcined clay cement), agro-residue ash, and construction-and-demolition waste powders, extending beyond traditional fly ash/slag.
Carbon Capture, Utilisation and Storage (CCUS)	Only pilot projects are considered because of the high cost and limited policy support.	CCUS is deployed at scale from the 2040s onward, capturing process CO_2 from large kilns by 2070.
Specific Energy Consumption (SEC)	In the context that Cement plants in India are among the global best, only 2% improvement is considered facilitated through increased use of Waste Heat Recovery.	This scenario envisages 8% improvement in SEC enabling through the deployment of advanced precalciner designs, full WHR coverage, oxy-fuel kilns, and digital optimisation. Electrical efficiency also improves via high-pressure grinding rolls and vertical mills.
Share of Captive/ Grid	Share of captive: 52% (2025) to 50% (2070), reflecting conservative views wherein the industry adds significant captive fossil capacity to meet the electric needs reliably.	Share of captive: 52% (2025) to 34% (2050) and 20% (2070), reflecting a gradual increase towards the use of Grid, which is assumed to be low-carbon and reliable.
Captive Fuel Mix	Coal-based generation: 90% (2025) to 52% (2050) and 40% (2070), wherein coal continues to be the dominant source owing to reliability concerns.	Coal-based generation: 20% (2050) and phased out by 2070 due to priority shift towards renewables driven by ambitious targets through CCTS, tightening of taxonomy thresholds and decline in storage costs for deploying RTC renewables.

Results

Energy Consumption: The cement sector's final energy demand increases substantially in both scenarios as clinker and cement output grow. Total final energy use rises from about 27 Mtoe in 2025 to around 86 Mtoe in 2050 and 98 Mtoe in 2070 under Current Policy Scenario, and 81 Mtoe in 2050 and 89 Mtoe in 2070 under Net Zero Scenario (see Figure 3.9). This represents a less than four times increase under the CPS and around three times increase under the NZS relative to 2025, with savings in the latter scenario coming from deeper efficiency gains, lower clinker ratios and higher use of supplementary cementitious materials. The difference in total energy consumption between CPS and NZS is modest, as both scenarios still require high-temperature kilns, so even a highly decarbonised cement system remains energy-intensive.

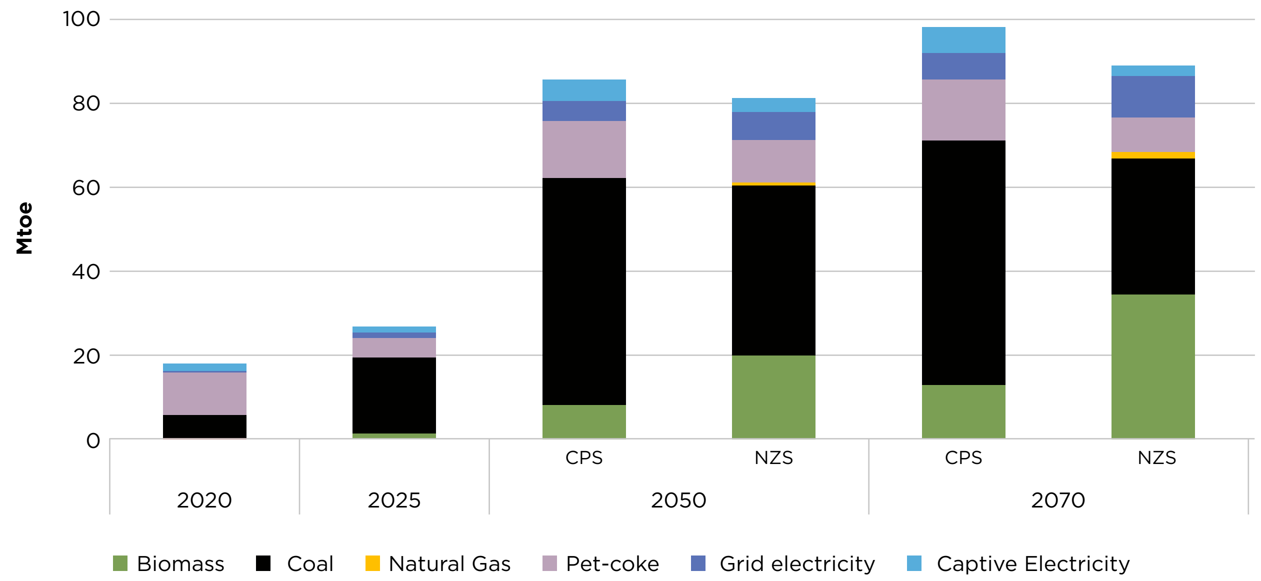

Figure 3.9: Final energy consumption in cement sector (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

By 2050, both scenarios show a gradual shift away from pure fossil fuels, but with very different end states by 2070. Under Current Policy Scenario (CPS), coal and petcoke continue to dominate the fuel mix, providing around 79% of total final energy in 2050 and about 74% in 2070 Vs 85% in 2025, with biomass and other alternative fuels playing a supporting role. Biomass would grow to only about 13% of final energy by 2070, while grid and captive electricity together would account for roughly 13%, mainly for grinding and auxiliaries. This pathway implies that most kilns would still run on conventional fossil fuels, with alternative fuels constrained by waste-supply logistics, quality issues, and weak policy push.

Under the Net Zero Scenario, the fuel structure is assumed to change in a transformative manner. By 2050, coal and petcoke's share of final energy would fall to about 62%, with biomass providing roughly 25%, and the remainder from electricity and a small share of gas. By 2070, biomass would contribute nearly 39%, while coal and petcoke's share drops to 46%. Electricity would supply close to 14% of final energy enabled by electrified equipment and CCUS systems.

This shift to clean fuels is mirrored in the captive power mix under Current Policy Scenario, captive electricity in 2070 is projected to be about 60% coal-based and the remaining 40% RE-based. Under NZS, captive supply becomes majority non-fossil by 2050 (only 20% coal) and is fully non-fossil-based (including nuclear) by 2070.

These patterns imply that NZS requires not only technology change inside the plant (low-clinker binders, CCUS-ready kilns) but also robust waste and biomass supply chains, co-processing infrastructure, and coordination with the power sector to deliver firm low-carbon electricity.

Emission Intensities

Emissions intensity declines over time in both scenarios, but with a deeper reduction projected under the Net Zero Scenario (NZS). In Current Policy Scenario (CPS), intensity is projected to fall by 10% in 2050 and by 21% in 2070 from 0.61 tCO_2/t cement in 2025 (see Figure 3.10). Under

NZS, emission intensity is projected to fall by 26% by 2050 and 39% by 2070 as compared to its value in 2025, reflecting the combined impact of lower clinker ratio and higher share of clean fuels. Remaining emissions (majorly process emissions) in NZS will be captured through carbon capture technologies to achieve full decarbonisation of the sector.

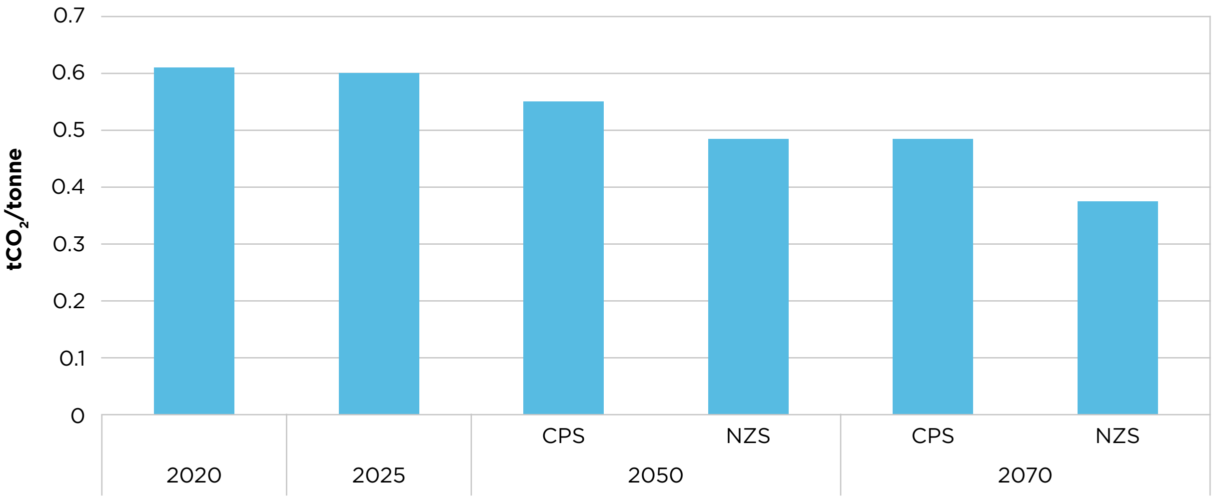

Figure 3.10: Emission intensity of cement sector (tCO_2/t) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Barriers and Enablers for Cement Sector Energy Transition

Challenges

a. **High dependency on conventional fuels:** for its thermal energy needs, as the clinker calcination process requires high-calorific-value fuels capable of sustaining consistently high kiln temperatures. In 2020-21, these fuels accounted for ~95% of the energy demand in the production process (GCCA India-Teri, 2025).

b. **High process emissions:** The calcination process to produce clinker alone contributes to 57-60% of the total emissions, followed by process heating accounting for 27-30% (GCCA India-Teri, 2025). International experience shows that The capture cost of cement plants is around USD 60-110 per tonne of CO_2 avoided (IEAGHG, 2019).

c. **Limited adoption of new technologies:** Existing Indian plants based on older rotary kilns have higher energy intensity, and with very limited adoption of new technologies like waste heat recovery systems (WHR) or pre-heaters for increasing efficiency. Only 70% large cement plants out of 250 have WHR systems installed (EPCWorld, 2021). The challenge includes higher capital cost for smaller capacity plants and a lack of financial incentives.

d. **Limited financing availability:** Depending on the WHR potential and the type of technology adopted, the current installation cost stands at USD 1.4- 1.5 million per MW in India (Mercomindia, 2023). Even emerging options such as carbon capture, utilisation and storage (CCUS) remain very expensive. Significant capital will therefore be required to support the low-carbon transition, including kiln electrification, green-hydrogen-based kilns, pre-processing of low-carbon alternative fuels, and the processing of new clinker substitutes or novel binders.

Suggestions

a. **Scale up alternative fuels:** Creating a dedicated supply chain of segregated waste for replacing coal and petcoke can encourage the adoption of waste-derived fuels from municipal solid waste, plastic wastes, used tyres and industrial wastes.

b. **Incentivise WHR:** Incentivise adoption of WHR through recognition of WHR under Renewable Consumption Obligations (RCOs).

c. **Green Public Procurement (GPP) for infrastructure projects:** Introducing GPP for infrastructure projects can create an assured demand for low-carbon cement products such as LC3.

d. **Harmonisation of Cement Taxonomy:** Aligning proposed Indian definitions of “Low-carbon cement” with international taxonomies will safeguard competitiveness in global markets.

e. **CCUS:** To address unavoidable process emissions in this sector, CCUS may be prioritised, beginning with large modern plants, and supported by shared infrastructure, targeted incentives, and robust regulatory frameworks.

3.2.3 Aluminium

Projections for Aluminium Production

Aluminium production in India is projected using a saturation-growth model, consistent with the methodology described in Section 3.1, and analogous to projections for other stock-driven materials such as steel and cement. Historically, per-capita aluminium consumption has increased with income and industrialisation, and then plateaued as economies matured. In this study, the model correlates historical aluminium use with per-capita GDP and applies high-income benchmarks to define the saturation levels.

India’s per capita aluminium consumption is currently around 3–4 kg, compared to the global average of 11-13 kg and China’s 25-30 kg, indicating vast headroom for growth (Aluminium Extrusion Manufacturers Association India, 2025).

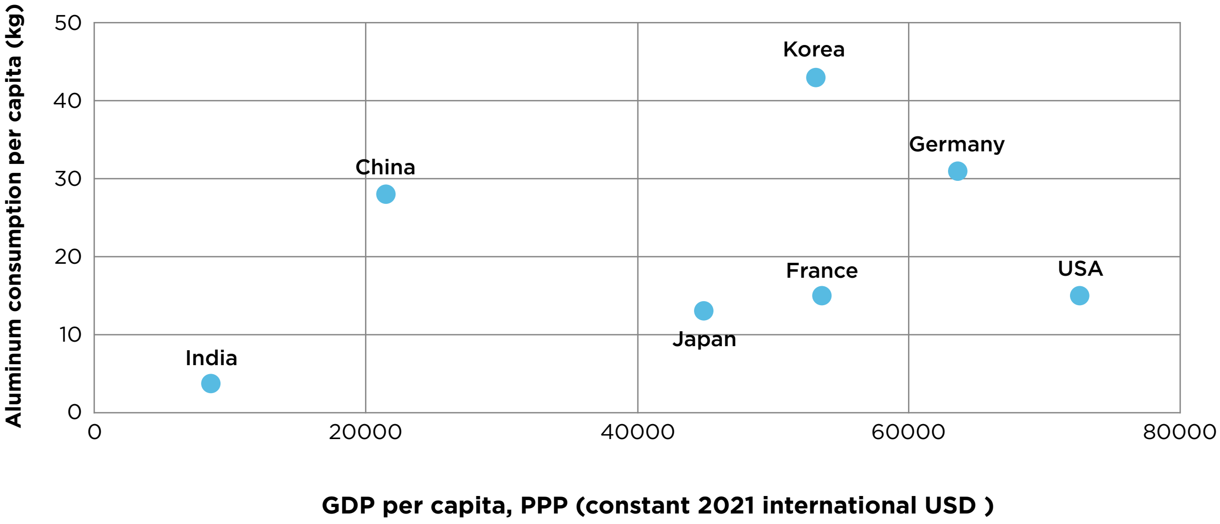

Figure 3.11: Global comparison of GDP/capita vs aluminium use/capita

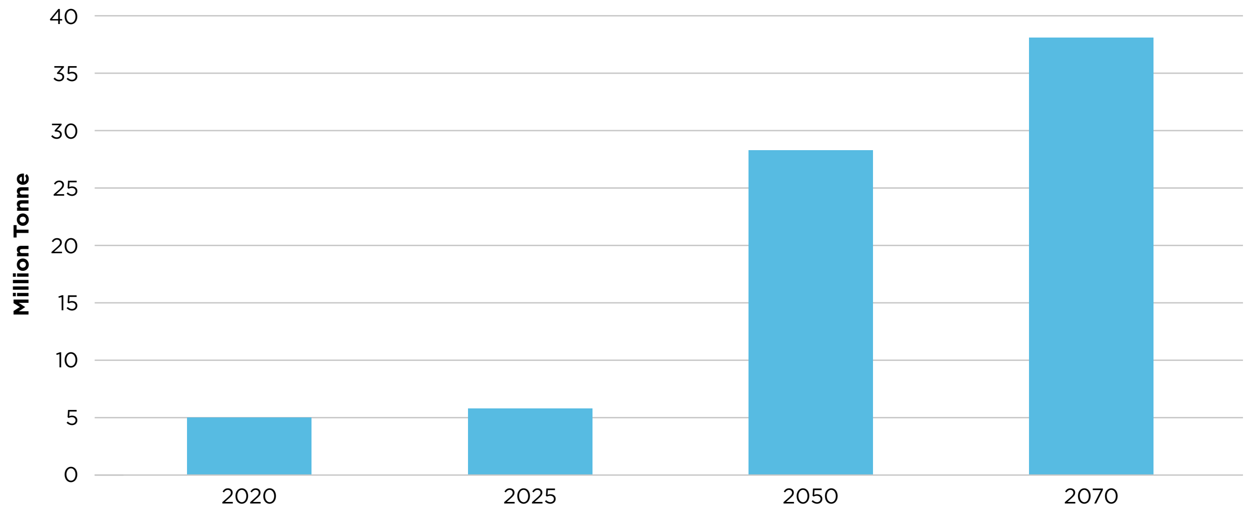

Figure 3.12: Aluminium production (million tonnes)

With rising incomes and the push for industrialisation through Make in India and PLI schemes, aluminium-intensive sectors such as power, infrastructure, transport (EVs, rail, aviation), construction, packaging, and consumer durables are expected to grow. Aluminium demand is accordingly expected to grow steeply and then gradually taper by mid-century. Modelling results suggest that per-capita consumption could reach ~23–24 kg by 2070. With this, the total aluminium production in India is projected to reach around 38 million tonnes by 2070 (see Figure 3.12).

Growth would be stronger, especially through the next three decades, supported by India's industrialisation and programs such as Make in India, PLI schemes, and the expansion of renewables and electric mobility, all of which are aluminium-intensive. Such growth underlines the need to plan for corresponding capacity expansion and resource supply (bauxite, power) or increased imports.

Scenarios

Two scenarios are examined for the Aluminium sector: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS), which diverge mainly in the degree of technology adoption and emission-mitigation ambition (See Table below)

Table 3.3: Scenario assumptions for aluminium sector

	Current Policy Scenario	Net Zero Scenario
Share of Scrap	Share of scrap remains at the 2025 level of 30% through 2070.	Share of scrap is assumed to increase from 30% in 2025 to 40% by 2070
Anode Technology	Remains same	Adoption of inert anodes leading to a deep reduction in process emissions
Specific Energy Consumption (SEC)	Improvement of 7.5% over 2025 through a moderate increase in the use of non-fossil sources for electricity generation	Improvement of 15% over 2025 through a rapid increase in the use of non-fossil sources for electricity generation and reaching global best efficiency standards
Share of Captive/ Grid	Share of captive: 80% (2025) to 74% (2050) and 70% (2070), reflecting conservative views wherein the industry adds significant captive fossil capacity to meet the electric needs reliably.	Share of captive: 80% (2025) to 57% (2050) and 40% (2070), reflecting a gradual increase towards the use of Grid, which is assumed to be low-carbon and reliable.
Captive Fuel Mix	Coal-based generation: 99% (2025) to 53% (2050) and 40% (2070), wherein coal will support the captive RE owing to reliability concerns.	Coal-based generation: 20% in 2050 and phase out by 2070 due to the shift towards renewables and captive nuclear driven by ambitious targets through CCTS, tightening of taxonomy thresholds

Results

Energy Demand: While final energy demand rises strongly in both scenarios, its scale and composition are expected to differ. Under the Current Policy Scenario (CPS), total final energy use is expected to grow by almost six times from about 7.2 Mtoe in 2025 to 44 Mtoe in 2070. Under the Net Zero Scenario, it would increase five times relative to 2025, reaching 37 Mtoe in 2070, a reduction of 16% compared to CPS (see Figure 3.13).

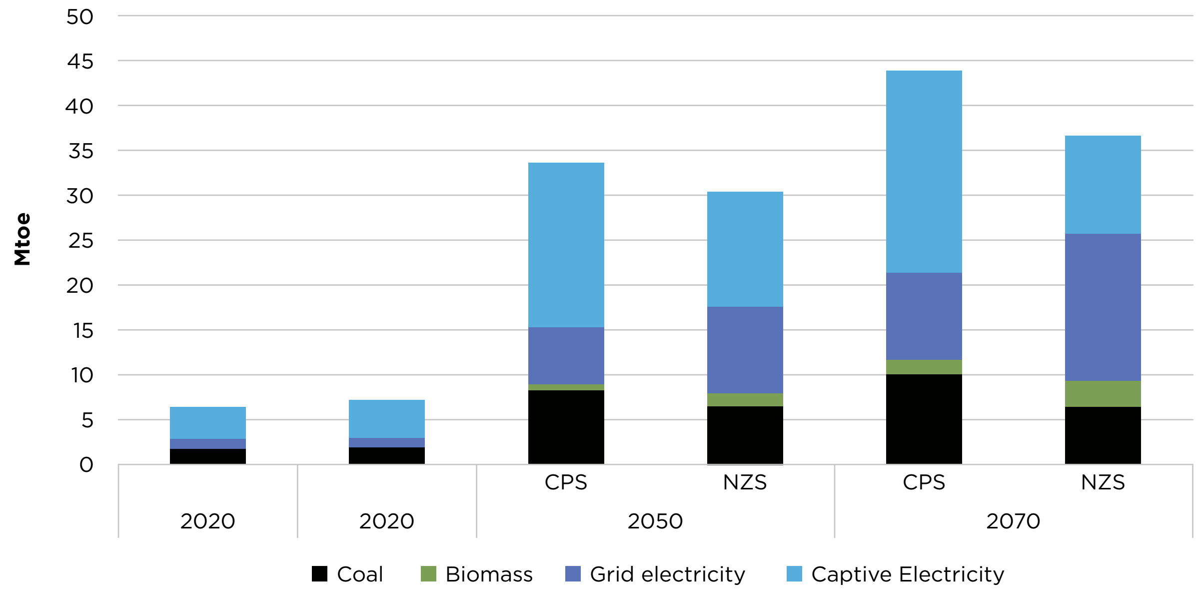

Figure 3.13: Final energy consumption in aluminium sector (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

The Net Zero Scenario (NZS) pathway moderates this growth in energy consumption through stronger efficiency improvements and a higher share of scrap aluminium. Even under the NZS, aluminium remains one of the most energy-intensive industrial sectors, which implies that its low-carbon transition would be closely tied to the pace and direction of the power sector's transition.

Fuel Mix:

Final energy use in aluminium is already electricity-heavy (73% in 2025) and continues to be dominant; the key difference is how that electricity is produced. In Current Policy Scenario, captive power remains dominant, with a significant share of coal. Non-fossil captive power (RE+ BESS) rises to 60% of the captive mix by 2070.

In Net Zero Scenario, electricity sourcing shifts steadily toward cleaner grid and non-fossil-dominant captive sources. By 2050, around 80% of captive generation is non-fossil (80% renewables and 20% nuclear), and by 2070, captive power is effectively 100% non-fossil, split between 70% renewables and 30% nuclear (SMRs). This implies that deep aluminium decarbonisation is contingent not only on efficiency and scrap, but on securing large volumes of firm low-carbon power.

Emission Intensity

Emissions intensity is expected to fall in both scenarios, but Net Zero Scenario (NZS) would deliver far deeper reductions. From an average intensity of 23.5 tCO_2/t aluminium in 2025, the Current Policy Scenario (CPS) reduces emissions intensity by about 36% by 2050 and around 58% by 2070, while NZS could achieve a 58% reduction by 2050 and around 90% by 2070 (see

Figure 3.14). Achieving the NZS trajectory implicitly requires higher secondary aluminium shares, deeper efficiency gains, a fully decarbonised captive power mix, and diffusion of low-emission process technologies (such as inert anodes) to curb non-CO_2 emissions.

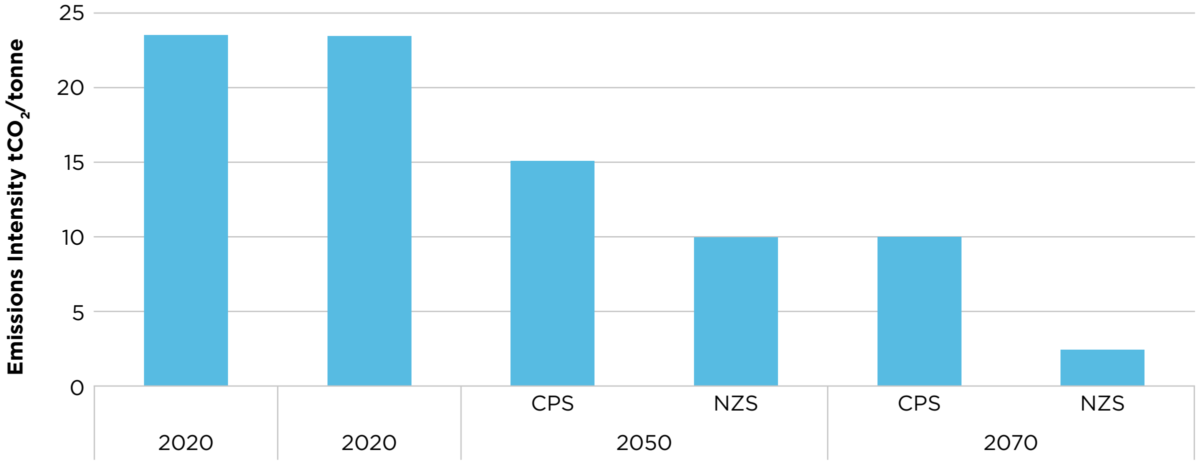

Figure 3.14: Emission intensity of aluminium sector (tCO_2/t) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Barriers and Enablers for Aluminium Sector Energy Transition

Challenges

a. **Depleting high-grade bauxite ore:** Given the shortage of bauxite ore, India needs to look towards other available resources such as aluminium laterites, high silica and high iron bauxites, which require additional processing for the production of alumina (Nandi, 2025).

b. **Challenges for bauxite sourcing:** A significant portion of India's bauxite reserves lies in indigenous community areas in Odisha, Jharkhand, and Chhattisgarh. Mining raises livelihood issues.

c. **Emission intensive:** The aluminium sector in India has a higher emission intensity of 23.5 tCO_2 per tonne, far above the global average of ~16 tCO_2/t due to coal-dependent electricity generation.

d. **Low recycling rate:** India's recycling rate for aluminium products is around 25%, well below the global average of around 60% (Shashikala, 2019).

e. **Import duty disparity:** The import duty on aluminium scrap is currently 2.5%, while it is 7.5% for the primary metal. This makes imported scrap attractive, which subsequently restricts local recycling (NITI Aayog, 2018).

f. **Retrofitting or replacing carbon anodes:** with inert ones is 9% more expensive than conventional approaches (WEFORUM 2023). Inert anode technology is still at the pilot stage.

Suggestions

a. **Promote low-carbon, reliable electricity supply:** Promoting a mix of RE + Storage and Nuclear to ensure reliable power. The cost differentials need to be addressed through specialised project structuring like use of Blended finance, Contract for Differences (CfD), and Joint Ventures with Technology developers.

b. **Revise taxation/duty rules:** to promote the domestic recycling industry.

c. **Reuse waste and by-products:** from aluminium production by promoting industrial symbiosis- 1 tonne of aluminium production results in 2-3 tonnes of bauxite residue and 2-5 tonnes of coal ash. These products can be utilised as feedstocks for cement production and as construction material (Banerjee, 2017). Incentivising the offtake of aluminium waste products may promote industrial symbiosis.

3.2.4 Textile

Projections for Textile Production

Future textile production in India is projected using a saturation-growth model, consistent with the methodology described in Section 3.1. Historically, per-capita textile consumption rises with income and urbanisation, then levels off as wardrobes saturate and lifestyles stabilise. For India, the model links historical fibre uses to per-capita GDP and applies international benchmarks to define long-run saturation levels. India's current per-capita textile consumption is only 5 kg per year, compared with 15 kg globally, indicating substantial potential for growth (Gupta, 2025). As incomes rise, urbanisation deepens, and apparel and technical textile segments expand, total fibre production is projected to increase from around 8 million tonnes (Mt) in 2020 to 53 Mt by 2050 and 61 Mt by 2070 (see Figure 3.15). While the demand increases by 8 times by 2070, the product mix is likely to tilt more towards technical and MMF-based textiles, altering energy profiles (more electricity-intensive processes) and increasing the importance of reliable, low-carbon power.

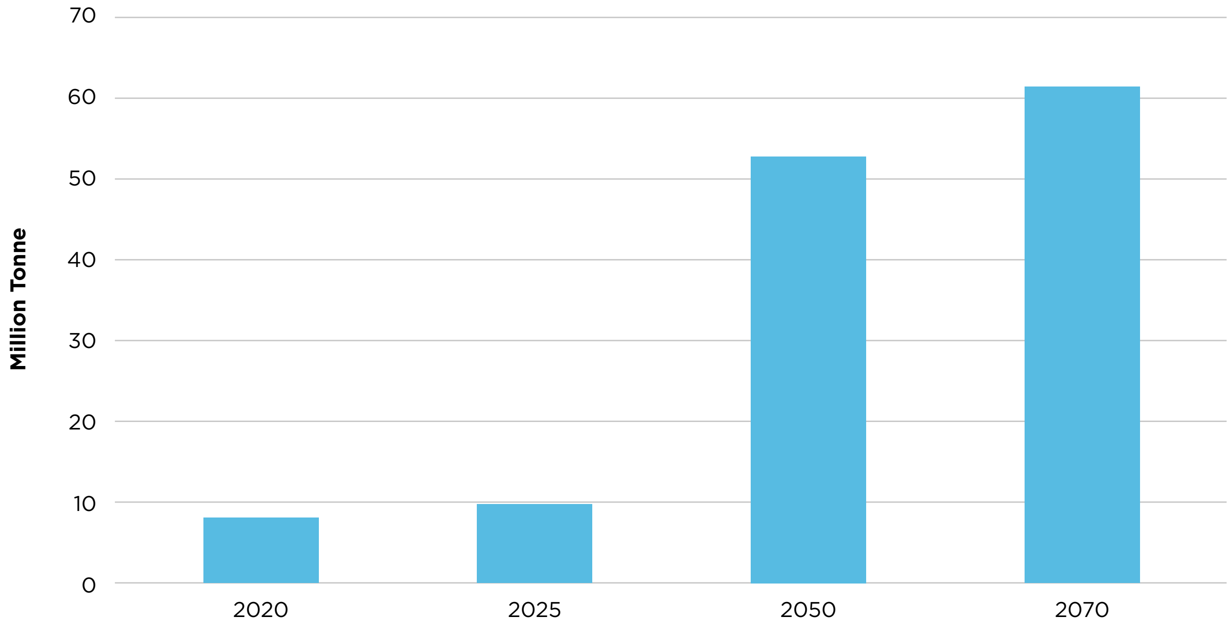

Figure 3.15: Textile sector production (million tonnes)

Scenarios

Two scenarios are examined for the Textile sector: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS), which diverge mainly in the degree of technology adoption and emission-mitigation ambition (See Table below)

Table 3.4: Scenario assumptions for textile sector

	Current Policy Scenario	Net Zero Scenario
Share of MMF vs Natural Fibres (Cotton Dominant)	Share of MMF is expected to improve from 27% in 2023 to 70% by 2070, driven by the government's dedicated technical textiles mission and evolving consumer preferences. This shift also aligns with the global fibre mix, where MMF account for almost 72% in 2022. The projections also account for land constraints, especially for growing cotton, and assume that average cotton yield will also improve by three times from 450-500 kg/ha (China's current yield: 2172 kg/ha in 2024)	
Specific Energy Consumption (SEC)	Improvement of 20% over 2025 through incremental upgrades in MSMEs and gradual diffusion of efficient motors, improved controls, and better steam/heat management	Improvement of 27% over 2025 through broader deployment of best-available technologies (VFDs, efficient looms, low-liquor dyeing, heat recovery, and digital process optimisation)
Electrification of the Thermal Process	Limited electrification of thermal processes and continued reliance on steam boilers	Accelerated electrification through the use of heat pumps and electric boilers supported by policy incentives and stricter emissions standards.
Share of Captive/Grid	**Share of captive:** 35% (2025) to 32% (2050) and 30% (2070), reflecting conservative views wherein the industry adds significant captive fossil capacity to meet the electric needs reliably.	**Share of captive:** 35% (2025) to 26% (2050) and 20% (2070), reflecting a gradual increase towards the use of Grid, which is assumed to be low-carbon and reliable.
Captive Fuel Mix	**Coal-based generation:** 80% (2025) to 50% (2050) and 40% (2070), wherein coal continues to be the dominant source owing to reliability concerns.	**Coal-based generation:** 20% (2050) and 0% (2070) due to a priority shift towards renewables driven by a decline in storage costs for deploying RTC renewables.

Results

Energy Consumption: Final energy consumption in the textiles sector is projected to rise strongly in both scenarios as fibre demand grows and processing volumes expand. Total final energy use increases from about 7.8 Mtoe in 2025 to 5.4 times under Current Policy Scenario (CPS) versus 4.5 times under Net Zero Scenario (NZS) by 2070 (see Figure 3.16). The NZ pathway moderates this growth through sector-specific efficiency measures, faster modernisation of MSME clusters, wider adoption of best-available spinning and weaving machinery, and process innovations in wet processing such as dope-dyed MMF (which avoids conventional dyeing), low-liquor and foam dyeing, and emerging supercritical CO_2 dyeing technologies that sharply cut steam and water use. In addition, greater recovery of waste heat from stenters and thermic fluid heaters, and gradual electrification of drying/finishing, reduce thermal energy demand per kg of fabric.

Fuel Mix: Under the Current Policy Scenario (CPS), coal remains the backbone of thermal energy and captive power. In 2050, coal continues to provide about 38% of total final energy (vs 40% in 2025), with 14% biomass supplementing it. By 2070, coal would supply around 36%, and the biomass share is projected to rise to 17%. In Net Zero Scenario (NZS), the thermal mix shifts decisively towards low-carbon sources. By 2050, coal's share in total final energy falls to 29%, while biomass rises to 28%. By 2070, coal is fully eliminated from both direct thermal use and captive generation, with biomass supplying more than half of total final energy, and electricity remaining, with captive power being 100% RE. This implies that textile low-carbon transition hinges on scaling up reliable biomass supply chains, RE for clusters, and shared modern boiler/steam infrastructure to serve MSME units.

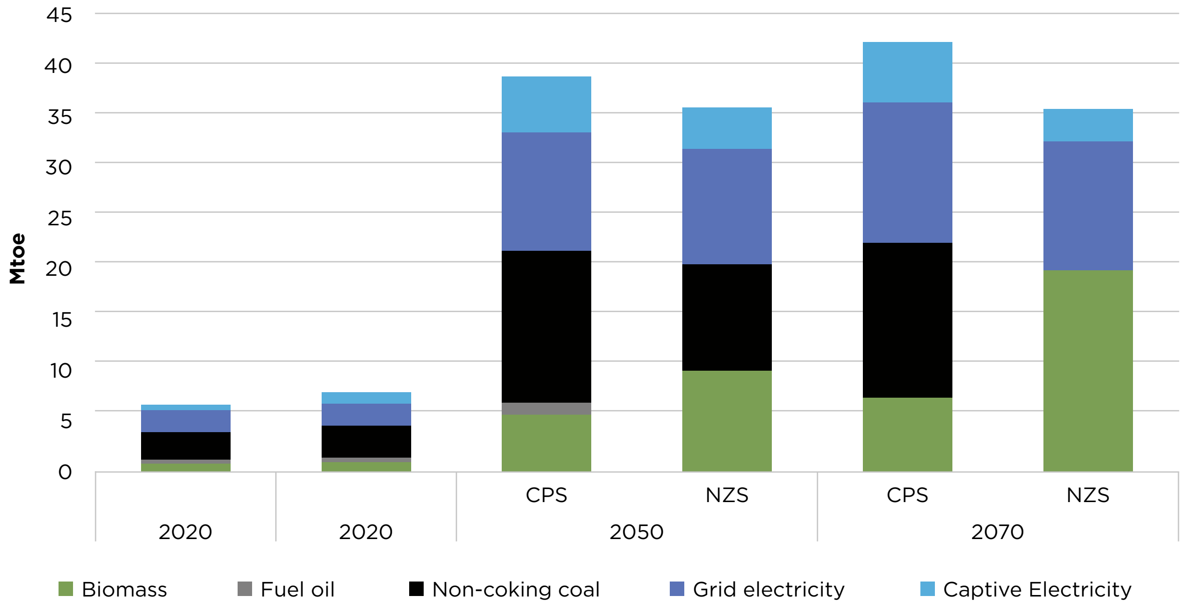

Figure 3.16: Final energy consumption in textile sector (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Emission Intensity: Under the Current Policy Scenario (CPS), emissions intensity reduces by around 41% by 2050 and about 66% by 2070 over 2025 levels. Under Net Zero Scenario (NZS), the reduction reaches 64% by 2050 and effectively 100% by 2070, approaching Net Zero emissions per tonne of textile output (Figure 3.17). Achieving this NZS trajectory requires the combined effect of Specific Energy Consumption (SEC) improvements, a complete phase-out of fossils from process heat and captive power, widespread renewable and biomass deployment in clusters, while increasing the use of circular and recycled fibres as final textile demand continues to grow.

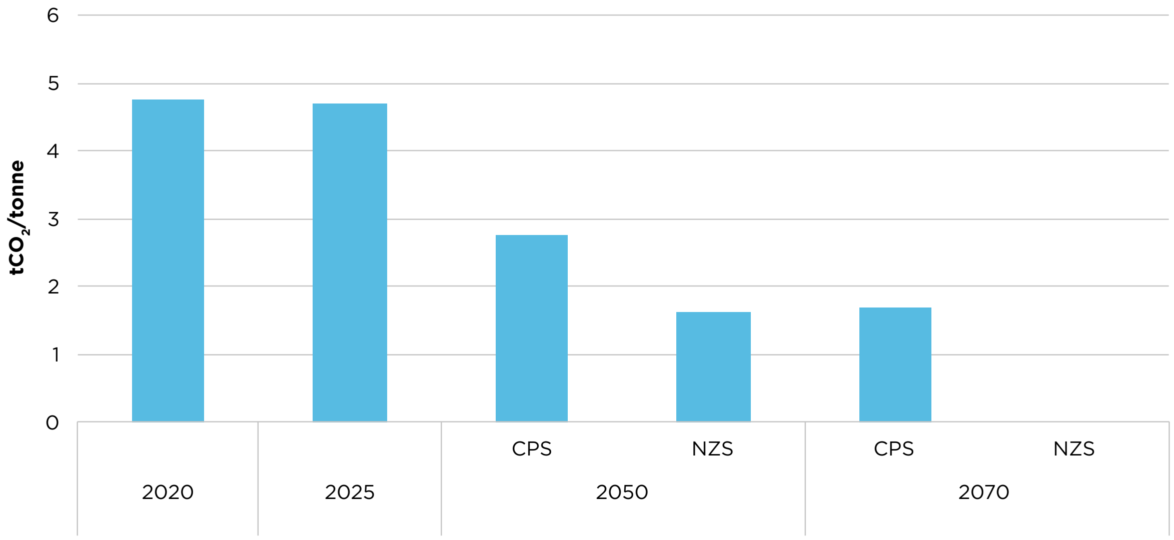

Figure 3.17: Emission intensity of textile sector (tCO_2/t) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Barriers and Enablers for Textile Sector Energy Transition

Challenges

a. **Dependence on fossils for thermal energy:** Industrial heat for washing, cleaning of cotton, bleaching and dyeing primarily comes from fossil fuels (Apparel Impact Institute 2025)

b. **High wastewater generation:** Dying and washing processes generate large quantities of wastewater (Holkar et al. 2016).

c. **Capital and technology gaps in fragmented SMEs:** India's textile sector consists largely of numerous small and medium enterprises (SMEs). These dispersed units often struggle to access affordable finance, acquire modern energy-efficient machinery, and keep pace with emerging low-carbon technologies and best practices

d. **Low adoption of advanced dyeing and finishing technologies:** Equipment such as digital/ink-jet printing and automated process controls is not commonly adopted, especially by older mills, leading to excessive energy and water use compared with best-practice benchmarks (Rahaman, 2024).

e. **Skill gap in the sector:** A large share of India's textile and apparel MSMEs lack the technical skills and capabilities for low-carbon transition, circular-economy practices, and ESG reporting, limiting their ability to adopt low-carbon technologies and access green finance (SwitchAsia, 2025).

Suggestions

a. **Promote sustainable fibres:** through product labelling enabled by digital passports targeting niche markets

b. **Scale ADEETIE scheme:** using ESCO/RESCO models, ADEETIE can bundle interest subvention, energy audits, DPRs, and M&V to deliver priority retrofits (e.g., heat pumps, variable-speed drives, waste-heat recovery) and on-site clean power with low upfront costs.

c. **Develop an electrification map:** linking temperature ranges, processes, and available electrification technologies.

d. **Promote circularity in the textile industry:** The textile industry generates tonnes of waste 7,793 kt annually (Recircle, 2025). Part of the projected demand can be met by recycled fibres, incentivised through product labelling and expanding the EPR framework, including setting recovery targets.

e. **Develop Lifecycle repository and Product Category rules:** to de-risk India's exports from emerging global developments, such as EcoDesign for Sustainable Product Regulations by the EU.

3.2.5 Paper and Pulp

Projections for Paper and Pulp Production

To project future demand, a statistical relationship is developed between per capita paper demand and GDP per capita. A linear regression model, explained in Section 3.1, is used for this. The regression parameters are derived from historical data of per capita paper production and GDP per capita. It is projected that Paper Production will increase with a CAGR of 2.5% between 2021-22 and 2069-70, reaching about 73 Mt in 2070 (Figure 3.18).

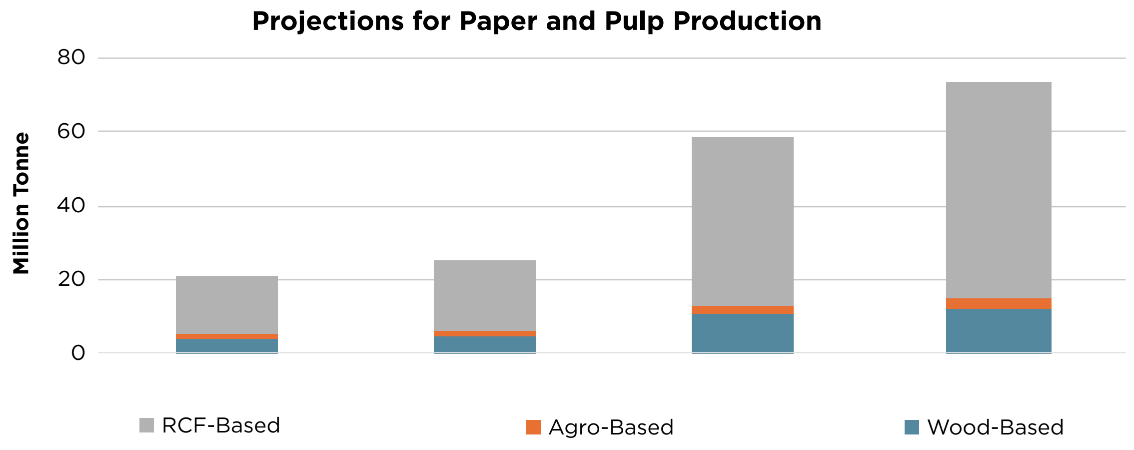

Figure 3.18: Projections for paper and pulp production (million tonnes)

Scenario Assumptions:

Two scenarios are examined for the paper and pulp sector: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS), which diverge mainly in the degree of technology adoption and emission-mitigation ambition (See Table below).

Table 3.5: Scenario assumptions for paper and pulp sector

	Current Policy Scenario	Net Zero Scenario
Share of Production using Wood/Agro/RCF	Remains the same as in 2025 across the years (RCF:75%, Wood:19% and Agro:6%)	Share of recycled fibre improves moderately by 2070 (RCF:80%, Wood:17% and Agro:3%)
Specific Energy Consumption (SEC)	Average efficiency improves to reach India's best available technology **Wood-based:** 1,400 kWh/t (Electrical) and 27.3 GJ/t (Thermal) **Agro-based:** 1,200 kWh/t (Electrical) and 27.3 GJ/t (Thermal) **RCF-based:** 600 kWh/t (Electrical) and 11.3 GJ/t (Thermal)	Average efficiency improves to reach the global best available technology **Wood-based:** 1,000 kWh/t (Electrical) and 27.3 GJ/t (Thermal) **Agro-based:** 1,200 kWh/t (Electrical) and 27.3 GJ/t (Thermal) **RCF-based:** 500 kWh/t (Electrical) and 11.3 GJ/t (Thermal)
Fuel Mix	**Share of electricity:** Improves from 20% (2025) to 38% (2050) and 53% (2070) **Share of biomass:** Improves from 16% (2025) to 18% (2050) and 20% (2070)	**Share of electricity:** Improves from 20% (2025) to 50% (2050) and 75% (2070) **Share of biomass:** Improves from 16% (2025) to 20% (2050) and 25% (2070)

Results

Energy Consumption

Final energy consumption in the paper and pulp sector is projected to rise in both scenarios as this sector expands. Based on the assumption highlighted above, the final energy consumption in the paper and pulp industry increases by more than three times from 10.9 Mtoe in 2025 to 33 Mtoe by 2070 in Current Policy Scenario (CPS) (see Figure 3.19). In Net Zero Scenario (NZS), the rise in energy consumption moderates due to higher electrification and efficiency improvements, including advanced process control, high-efficiency equipment, waste heat recovery, and increased use of cogeneration. Total final energy consumption in NZS is projected to reach 28.5 Mtoe by 2070, a reduction of 14% as compared to CPS.

Fuel Mix

In the Current Policy Scenario (CPS), while the share of clean energy increases, the fuel mix by 2070 remains partially reliant on fossil fuels, with around 30% of total energy consumption still derived from fossil sources. The share of electrical energy and biomass increases from 17% and 16% in 2023 to 35% and 18% in 2050 and 53% and 20% by 2070. In Net Zero Scenario (NZS), the industry undergoes a dramatic shift in fuel mix with fossil fuel being eliminated from both electricity generation and thermal use. Biomass supplies almost 25% of energy consumption, and the remaining 75% is shifted to electricity. Further, 100% of captive electricity used for operations is expected to come from renewable-based generation. This implies that low-carbon transition of the paper and pulp industry will require coordinated development of biomass supply chains, RE-enabled industrial clusters, increased use of recycled fibre, electrification of low and medium temperature process via common high-efficiency thermal infrastructure for MSMEs.

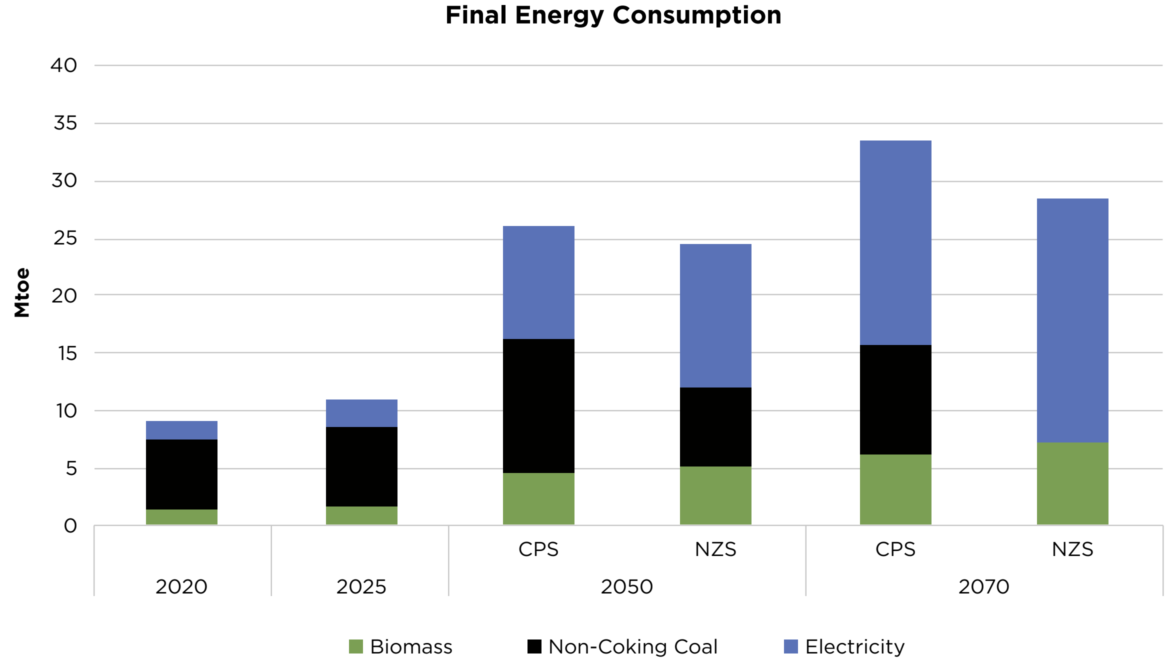

Figure 3.19: Final energy consumption in pulp and paper sector (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Emission Intensity: The emission intensity of paper and pulp industry production is around 1.98 tCO_2/t in 2025. Under the Current Policy Scenario (CPS), the paper industry remains a significant source of industrial CO_2 emissions till 2050. However, with the energy efficiency improvement and increased electrification and biomass penetration, the emission intensity will drop to 1.04 CO_2/t by 2070, a reduction of 48% from 2025 (Figure 3.20). In the Net Zero Scenario (NZS), emissions are reduced to near zero by 2070. This is achieved through rapid electrification using low-carbon electricity, higher improvement in Specific Energy Consumption (SEC) and higher penetration of cleaner fuel like biomass as compared to Current Policy Scenario.

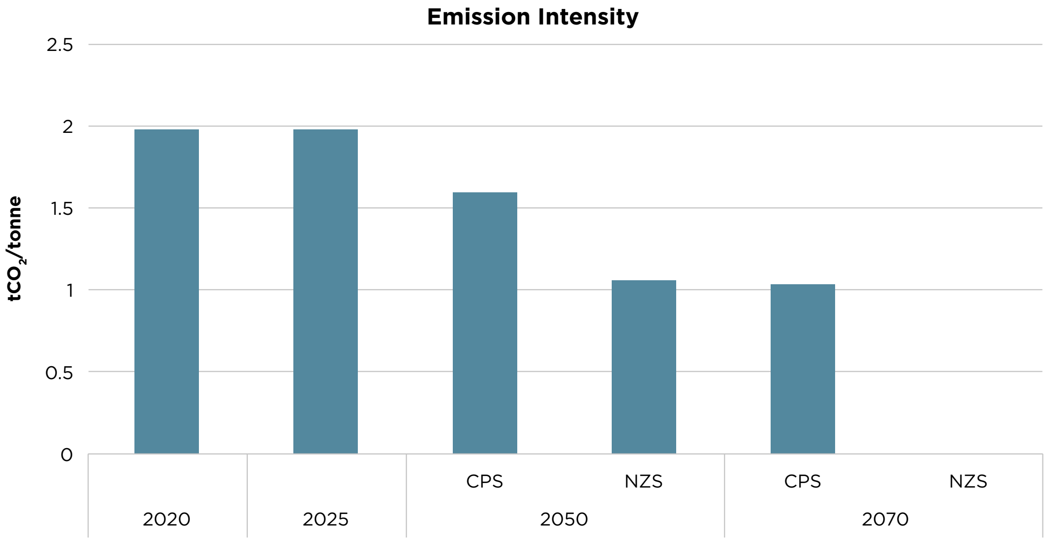

Figure 3.20: Emission intensity of paper & pulp sector (tCO_2/t) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Barriers and Enablers for Paper and Pulp Sector Energy Transition

Challenges

a. **High raw-material costs:** Waste paper, imported pulp, and wood chips remain expensive, forcing producers to raise product prices and face reduced profitability (Resourcewise 2024)

b. **Outdated technologies:** Outdated technologies that raise production costs, lower product quality, increase pollution, and limit economies of scale (GOI 2014).

c. **Capital-intensive boiler upgrades:** Installing modern recovery boilers requires heavy capex that many Indian mills cannot easily finance.

d. **Unreliable biomass and fibre supply:** Competition for agro-residues and plantation wood, coupled with seasonal availability and transport bottlenecks, makes it hard for mills to secure consistent low-carbon fuel and certified raw material.

e. **Low market demand for eco-labelled paper:** Domestic buyers rarely pay more for Forest Stewardship Council (FSC)-certified or low-carbon paper, lowering incentives for mills to invest in low-carbon transition.

Suggestions

a. **Energy efficiency improvement:** The pulp and paper industry needs to invest in energy-efficient technologies such as vacuum blowers, shoe presses, advanced process controls and monitoring, micro turbines, oxy-fuel lime kilns, waste heat, steam and condensate recovery, to enhance energy efficiency (IPPTA, 2023). The ADEETIE scheme can facilitate shift to use of these technologies, and scale can be achieved by deploying ESCO business models along with use of ADEETIE scheme benefits.

b. **Electrification of Steam:** use of electric boilers or high-temperature heat pumps to generate the large volumes of process steam (Joyo 2025). This can be supported by VGF till TCO parity. For electricity boilers, enable demand aggregation and access to low-cost RE electricity.

c. **Enhance Green Energy from use of Black Liquor:** Integrated pulp and paper mills should increase the solid concentration of black liquor to 72–73 % before firing in recovery boilers. Higher-solid firing raises the liquor's calorific value, allowing mills to generate more renewable steam and electricity (India GHG Program 2016).

3.2.6 Ethylene

Projections for Ethylene Production

Future ethylene production in India in 2047 is projected to reach about 31 million tonnes, applying a CAGR of 7.4%, observed over the last decade. Beyond 2047, as India's demand growth stabilises, ethylene production is assumed to approach saturation and grow at a much slower rate. As shown in Figure 3.21, total ethylene production in India is projected to reach approximately 38 million tonnes per year by 2070.

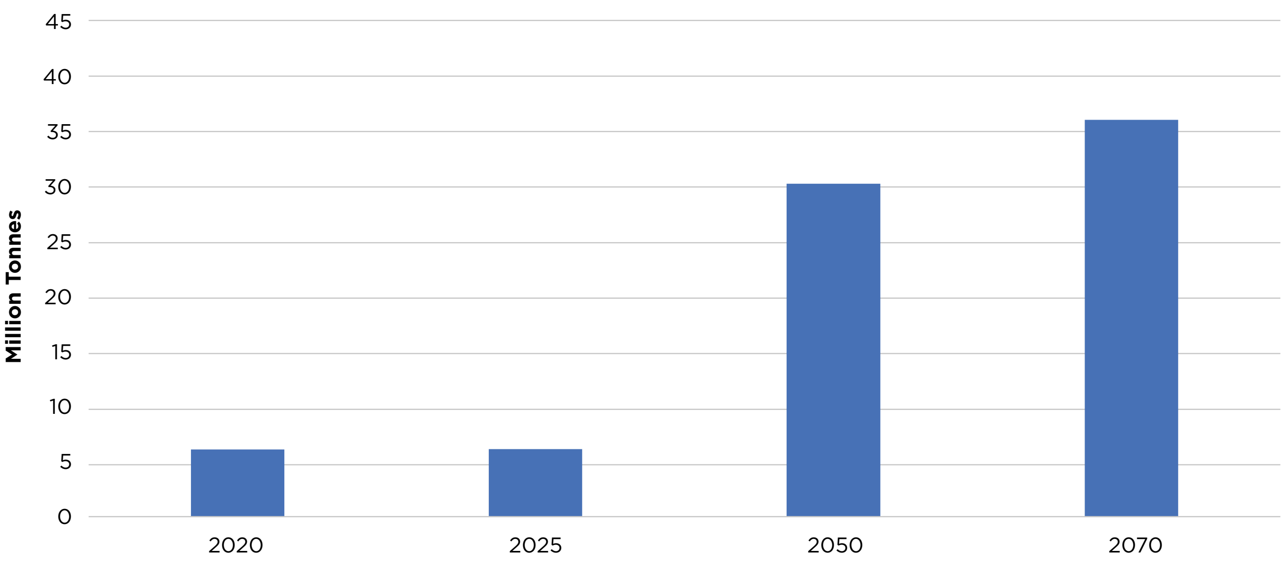

Figure 3.21: Projection of ethylene production in India (million tonnes)

Scenario Assumptions

Two scenarios are examined for the Ethylene sector: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS), with differences explained in the table below.

Table 3.6: Scenario assumptions for ethylene sector

	Current Policy Scenario	Net Zero Scenario
Share of Production using Naphtha vs Ethane	**Share of Ethane:** improves marginally from 55% in 2025 to 60% by 2070	**Share of Ethane:** improves from 55% in 2025 to 65% by 2050 and 70% by 2070. Growing use of ethane-based production is driven by superior cost economics, higher ethylene yields, lower capital requirements, and a comparatively smaller carbon footprint
Fuel Mix	**Captive/Grid electricity:** Share of captive moderately declines from 80% in 2025 to 50% by 2070. Further, within captive, from dominantly fossil in 2025, there will be a gradual shift towards non-fossil fuels whose share increases to 60% by 2070.	**Captive/Grid electricity:** Share of captive declines from 80% in 2025 to 30% by 2070. Further, the entire captive power will be a non-fossil-based electricity system by 2070.

Results

Based on the assumption highlighted above, the final energy demand for ethylene production increases by 9 to 11 times from 17 Mtoe in 2025 to 100 Mtoe in Current Policy Scenario and 96 Mtoe in Net Zero Scenario (Figure 3.22). By 2070, the fuel mix for ethylene production in both scenarios remains predominantly fossil fuel-based due to the essential role of feedstocks in the production process.

Under the Current Policy Scenario (CPS), naphtha continues to be the dominant input, with natural gas use projected to increase. Electricity would contribute only a small share, primarily for operational needs rather than as a major energy source. Under the Net Zero Scenario (NZS), there is a marked shift from naphtha to natural gas, reflecting a move toward relatively cleaner fossil fuels. However, despite this shift and the gradual rise in electricity use, fossil fuels would still form the bulk of the energy mix, driven by the continued dependence on hydrocarbon feedstocks.

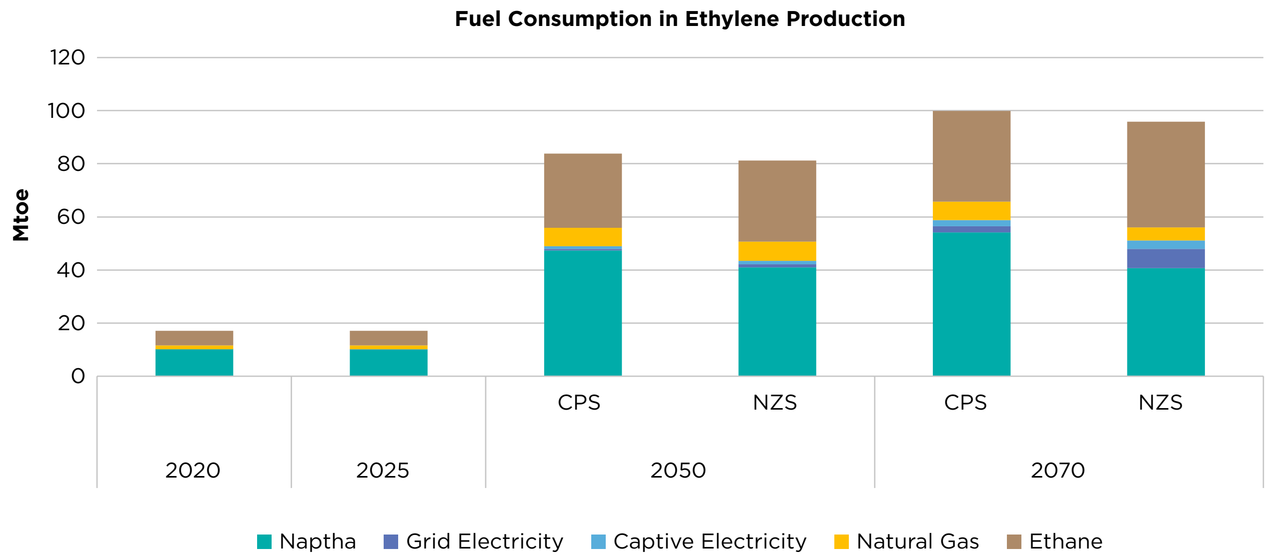

Figure 3.22: Final energy consumption in ethylene (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Emissions

The emission intensity of ethylene production in India is about 1.91 tCO_2/t in 2025. It includes both process emissions and energy-related emissions. In this sector, the process emissions account for more than 60% of the total emissions, which are difficult to mitigate and require carbon capture technologies. For the balance energy emissions, efforts like shifting fossil-fuel based thermal energy to electricity-based heat and utilising RE-based power in captive plants would be required. The emission intensity in Current Policy Scenario (CPS) is projected to reach 1.85 tCO_2/t of production. Under the Net Zero Scenario (NZS), this would reduce to 1.45 tCO_2/t due to greater efforts towards cleaner fuel and clean electricity (Figure 3.23).

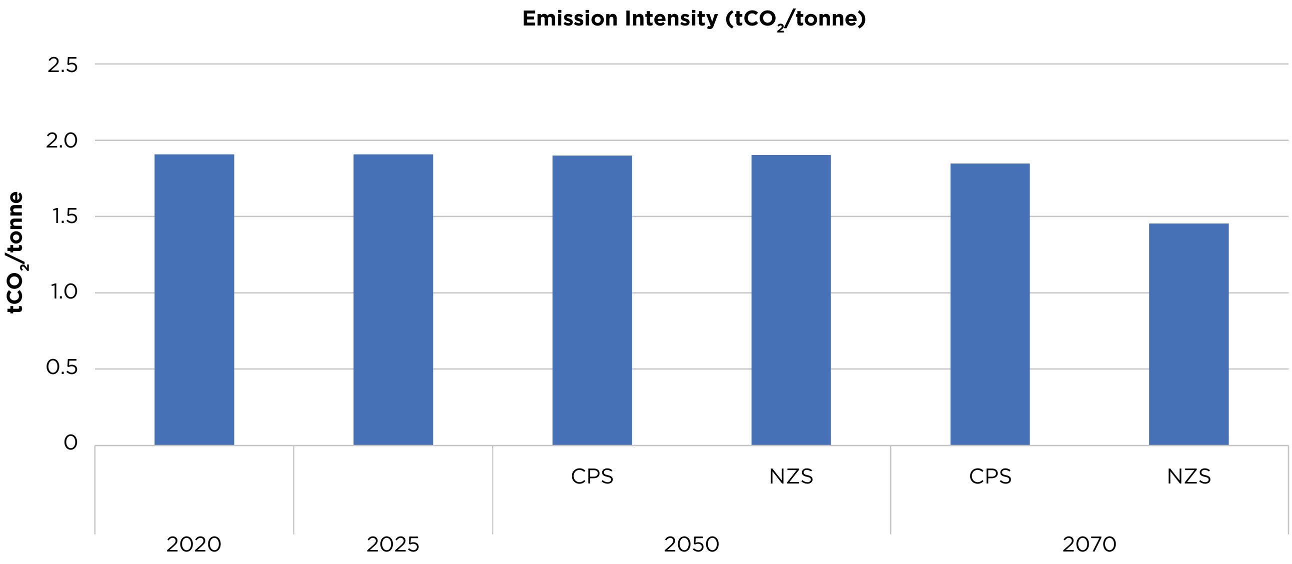

Figure 3.23: Emission intensity of ethylene sector (tCO_2/t) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Barriers and Enablers for Ethylene Sector Energy Transition

Challenges

a. **Dependence on fossil fuels for high-temperature heat:** Steam cracking requires heat exceeding 850°C, traditionally generated by burning fossil fuels (methane/off-gas) in furnaces, accounting for almost 90% of the process CO_2 emissions.

b. **High carbon footprint of feedstocks:** The sector relies heavily on fossil-based feedstocks (naphtha, ethane), which have embedded carbon. Naphtha route emits around 1.73 tCO_2 while the ethane route emits 0.76 tCO_2 per tonne of ethylene production, creating a significant carbon lock-in.

c. **High capital intensity and asset inertia:** Ethylene plants are massive, capital-intensive assets with long lifespans (30–50 years). Retrofitting these facilities for low-carbon technologies (like CCUS or e-cracking) requires large capital (WEF, 2024).

d. **Technological gaps in electrification scale-up:** While electric cracking is a promising alternative, it faces hurdles in heat management, material durability, and sourcing of stable green power. Commercial-scale deployment is still in the pilot/early-adoption phase (360iResearch 2025).

e. **Linear consumption and plastic waste:** The downstream use of ethylene (polyethene) generates large-scale plastic waste. India faces significant challenges in segregation and logistics, with contamination limiting the supply of quality feedstock for recycling (TERI, 2021).

f. **Process emissions and flaring:** Beyond energy use, fugitive emissions and flaring during startup/shutdown contribute to the environmental footprint. CO_2 is also a byproduct in some reaction pathways, necessitating management.

g. **Skill and integration gap:** The shift to electric furnaces, hydrogen firing, and circular feedstocks requires new technical competencies. The current workforce lacks specialised skills in power electronics and in managing variable bio/waste feedstocks (ReAnIn, 2024).

Suggestions

a. **Switch to renewable process heat (Electrification):** Replace gas-fired furnaces with electric steam crackers (e-crackers) powered by RE to reduce emissions. (360iresearch 2025; ScienceDirect 2024).

b. **Adopt sustainable feedstocks:** Transition to bio-naphtha and bio-ethanol (dehydration to ethylene). Innovations in fermentation have improved yield efficiency by 30%, making bio-ethylene a viable low-carbon alternative (ReAnIn, 2024). Incentivise adoption through an assured offtake mechanism.

c. **Adoption of advanced separation technologies:** Replace energy-intensive distillation with membrane separation and adsorption technologies for olefin-paraffin separation. This reduces the energy demand for downstream purification, a major energy consumer in ethylene plants (IEA, 2024).

d. **Deploy Carbon Capture, Utilisation, and Storage (CCUS):** Install carbon capture units on cracker flue gas stacks. Captured CO_2 can be utilised to produce methanol or stored (WEF, 2024).

e. **Build capacity for Green Chemistry:** Establish industry-academia partnerships to train the workforce in electrochemistry, hydrogen safety, and circular supply chain management. Training programs must focus on the operational nuances of e-furnaces and handling variable quality recycled feedstocks (360iResearch, 2025).

3.2.7 Chlor-Alkali

Projections for Chlor-Alkali Production

The chlor-alkali sector analyses key products including Caustic Soda, Soda Ash, and Liquid Chlorine. Future demand is projected using a univariate regression model wherein per-capita demand is determined based on per-capita GDP. Based on this, Caustic Soda production is projected to increase with a CAGR of 5.3% between 2023-24 and 2049-50 and a CAGR of 3.31% between 2049-50 and 2069-70, reaching about 14 Mt by 2050 and about 27 Mt by 2070. About 18.8 Mt of liquid chlorine, a co-product of caustic soda, would be produced in 2070. Soda Ash production is projected to increase with a CAGR of 3.8% between 2023-24 and 2049-50, and a CAGR of 2.68% between 2049-50 and 2069-70, reaching about 8 Mt by 2050 and about 13 Mt by 2070 (Figure 3.24).

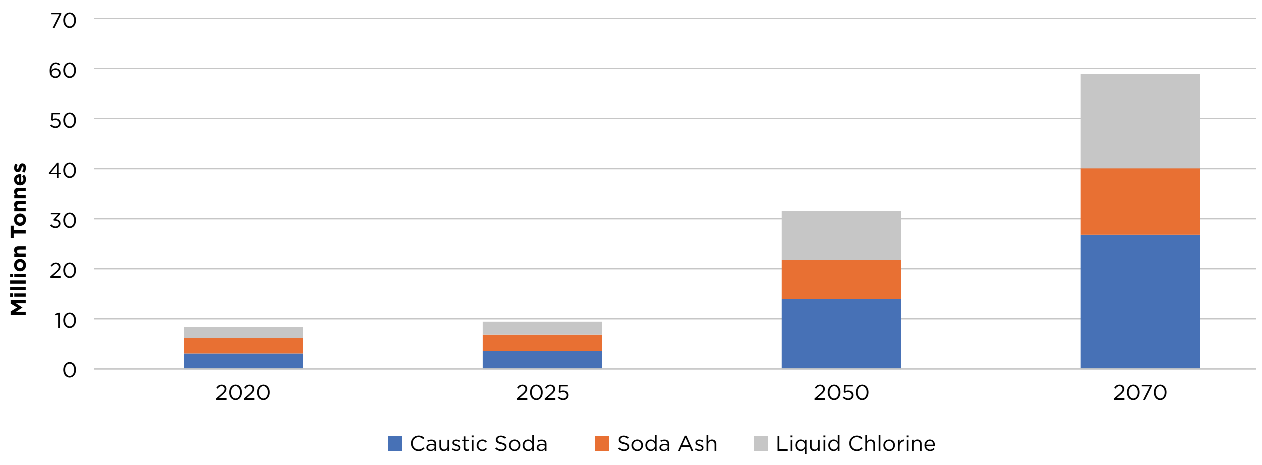

Figure 3.24: Chlor-Alkali products production (million tonnes)

Scenarios

Two scenarios are examined for the Chlor-Alkali sector: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS), with differences explained in the table below:

Table 3.7: Scenario assumptions for chlor-alkali sector

	Current Policy Scenario	Net Zero Scenario
Specific Energy Consumption (SEC)	Average efficiency improves to reach India's best available technology **Caustic Soda:** Improves from 15.5 GJ/ton in 2025 to 13.28 GJ/ton by 2070 **Soda ash:** Improves from 8.54 GJ/ton in 2025 to 7.61 GJ/ton by 2070	Average efficiency improves to reach the global best available technology **Caustic Soda:** Improves from 15.5 GJ/ton in 2025 to 11.72 GJ/ton by 2070 **Soda ash:** Improves from 8.54 GJ/ton in 2025 to 6.86 GJ/ton by 2070
Fuel Mix	**Captive/Grid electricity:** Share of captive declines from 80% in 2025 to 60% by 2070. Further, within captive, from dominantly fossil in 2025, there will be a gradual shift towards non-fossil fuels, whose share increases to 40% by 2070.	**Captive/Grid electricity:** Share of captive declines from 80% in 2025 to 40% by 2070. Further, the entire captive power will be a non-fossil-based electricity system by 2070.

Results

Final Energy Consumption

The final energy consumption for Chlor-Alkali (Caustic Soda+Soda Ash) increases from 2 Mtoe in 2025 to 11.7 Mtoe in Current Policy Scenario (CPS) and 9.4 Mtoe in Net Zero Scenario (NZS) by 2070. Figures 3.25 and 3.26 provide the fuel-wise consumption separately for Caustic Soda and Soda Ash. Electrification while increases from 44% in 2025 to 65% in CPS by 2070, the role is greater with almost 80% electrification in 2070 in NZS across the Chlor-Alkali Industry.

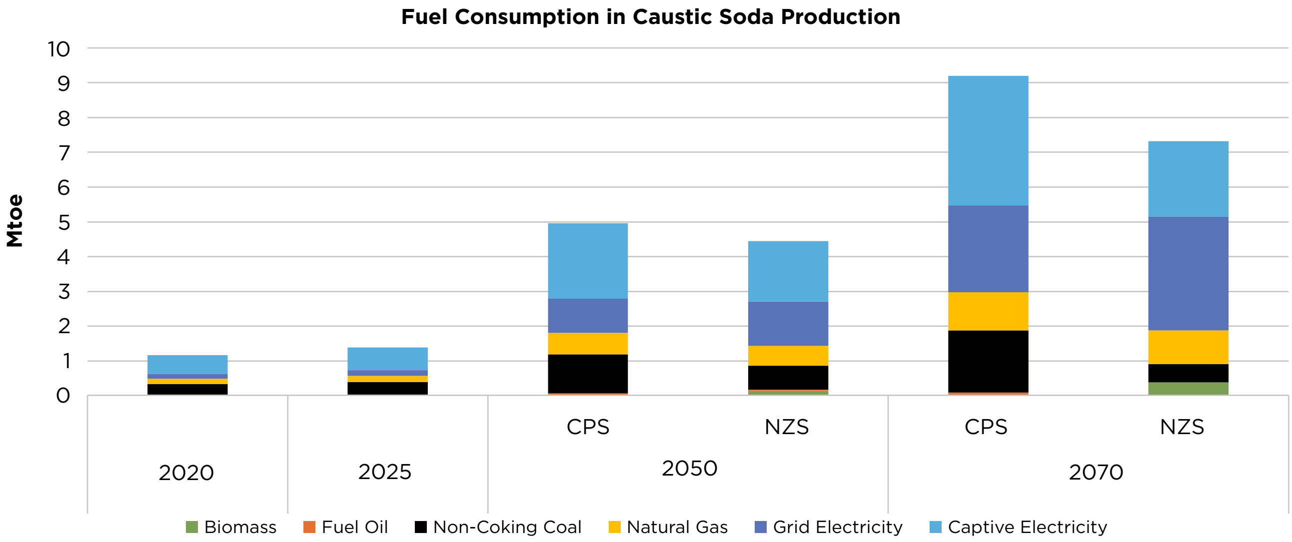

Figure 3.25: Final energy consumption in caustic soda industry (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

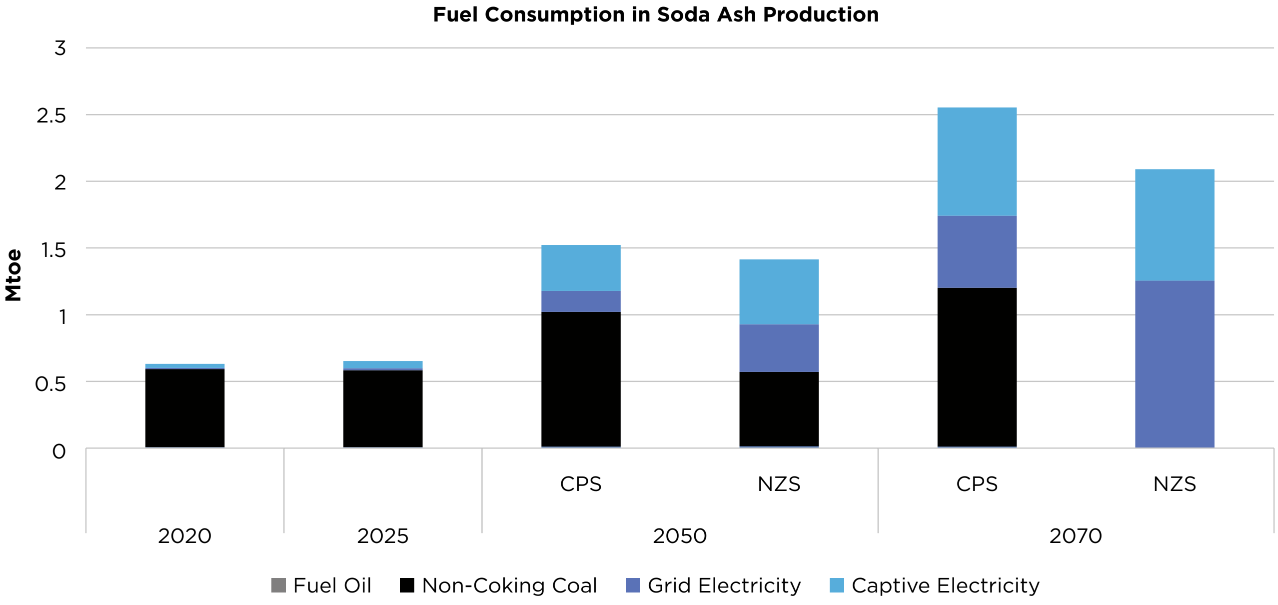

Figure 3.26: Final energy consumption in the soda ash industry (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Emission Intensity:

The emission intensity of caustic soda and soda ash production in India is 2.9 tCO_2/t and 1.28 tCO_2/t of production in 2025. Soda ash accounts for 25% of India's IPPU emissions. Under the Current Policy Scenario (CPS), emission intensities are expected to drop to 1.18 tCO_2/t for caustic soda and 1.05 tCO_2/t for soda ash in 2070. The chlor-alkali industry would thus remain a significant source of industrial CO_2 emissions even in 2070 (Figure 3.27).

In the Net Zero Scenario (NZS), emissions intensities in 2070 would be 94% lower for caustic soda and 74% lower for soda ash as compared to CPS. This would be achieved through rapid electrification using low-carbon electricity and greater improvement in SEC. The lower reduction in the case of soda ash is due to a continued rise in process emissions.

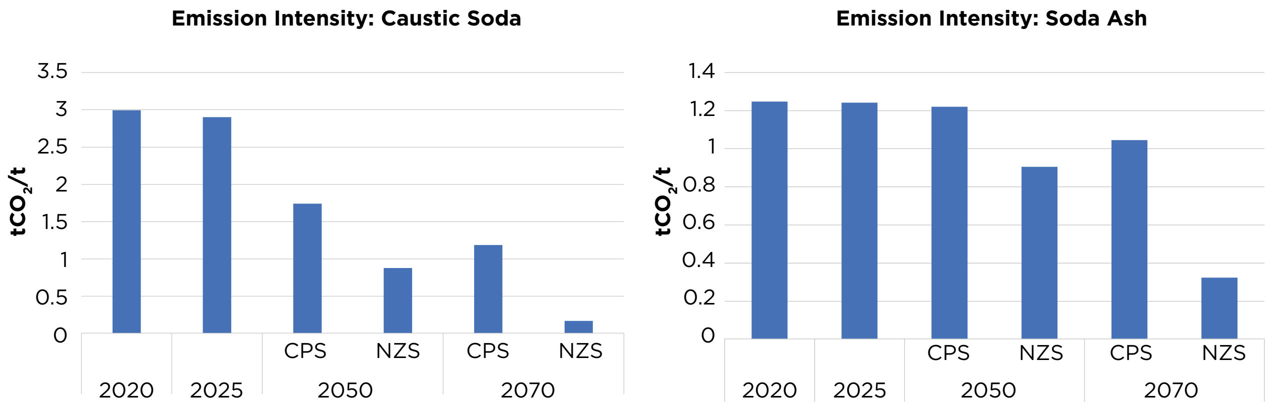

Figure 3.27: Emission intensities for caustic soda (left) and Soda Ash (right) (tCO_2/t) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Barriers and Enablers for Chlor-Alkali Sector Energy Transition

Challenges

a. **Emissions from coal-based power:** Although chlor-alkali production is electrified (JMK Research & Analytics, 2025), much of this is power sourced from the grid or coal-based captive sources, leading to significant Scope 2 emissions.

b. **High energy costs and price fluctuations:** Energy costs make up 60–70% of production costs, impacting industry competitiveness at the time of electricity price volatility.

c. **Surplus chlorine challenge:** Caustic soda production generates excess chlorine, but low downstream demand and its hazardous nature create storage and utilisation challenges (Harish, 2024).

d. **Underutilised hydrogen by-product:** Hydrogen generated as a by-product of brine electrolysis often goes underutilised or wasted.

e. **Brine quality issues:** The process requires purified water and high-quality brine; poor brine quality lowers efficiency and increases energy use, scaling and maintenance issues.

f. **Barriers for smaller manufacturers:** Small and medium-sized manufacturers lack the necessary resources to invest in energy-efficient technologies or renewable power, slowing overall sector-wide low-carbon transition.

Suggestions

a. **Shifting from mercury to advanced cell technology:** Shifting to membrane cell technology has already reduced 25% electricity consumption (Kermeli & Worrell, 2025). Further energy savings are possible with next-generation technologies like oxygen-depolarised cathodes (ODCs) and bipolar membranes, supported through R&D partnerships and providing tax benefits to early adopters.

b. **Flexible operations with RE:** Procuring RE through long-term PPAs, captive solar or wind projects or the RESCO model can cut emissions and reduce exposure to power price volatility.

c. **Utilising surplus chlorine in downstream industries:** Expanding downstream linkages to utilise surplus chlorine for PVC, solvents, or bleaching agents, leveraging shared infrastructure with the support of Industry groups such as the Alkali Manufacturers Association of India (AMAI). Researchers have found that setting up a 150,000 Mt/year PVC plant could use up to nearly 45% of residual chlorine from chlor-alkali plants in Bangladesh, and turn the waste problem into a feedstock solution, cutting storage risks and adding to profits (Roy et al, 2022).

d. **Utilising hydrogen for decarbonisation:** Generated hydrogen can be used to produce hydrogen peroxide or as fuel for power generation and fuel cell vehicles (Roy et al., 2022).

3.2.8 Fertiliser

Projections for Fertiliser Production

Fertiliser demand in India is projected using the methodology widely adopted and shared by the Fertiliser Association of India. The detailed methodology for arriving at projections for major fertiliser production in India through 2070 is provided in Annexure IV. Fertiliser use is derived from food grain requirements, which are estimated based on population growth projections. Based on this actual fertiliser nutrient requirement, demand and supply of major fertiliser products, namely urea, DAP, and complex fertiliser, have been projected (Figure 3.28).

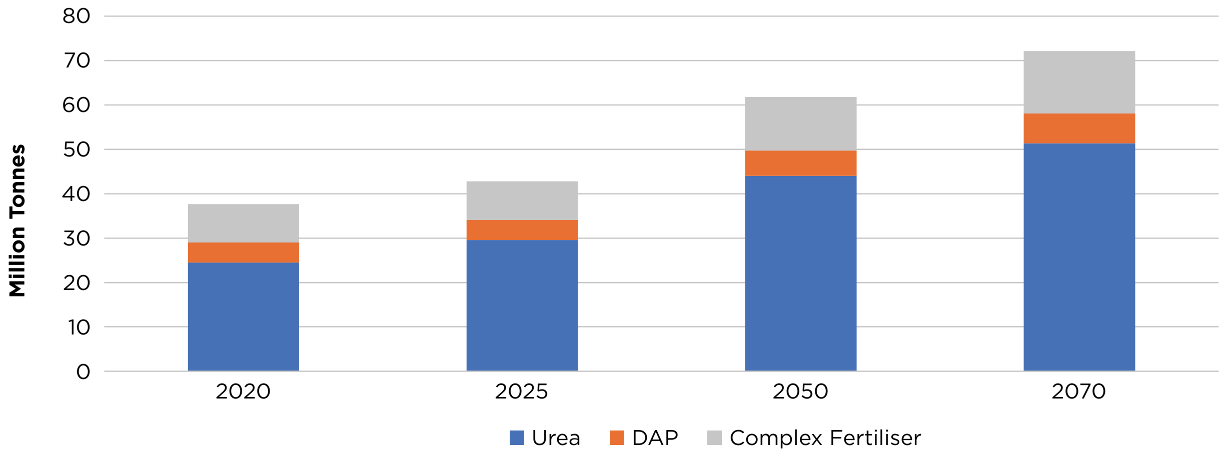

Figure 3.28: Major fertiliser products production (million tonnes)

Production of urea, DAP and complex fertilisers during 2023-24 was 31.41 Mt, 4.29 Mt, and 9.54 Mt, respectively. Based on the methodology described in the Annexure and assuming a level of self-sufficiency, indigenous supply projections of these major fertiliser products are estimated, as shown in Figure 3.28.

Scenarios

Two scenarios are developed to assess low-carbon transition pathways for the fertiliser sector: a Current Policy Scenario (CPS), reflecting continuation of existing policies and measured technology uptake, and a Net Zero Scenario (NZS) aligned with India's 2070 Net Zero emissions goal. Both scenarios assume the same growth in fertiliser production but differ fundamentally in their assumptions of energy efficiency, fuel use and electricity sourcing.

Table 3.8: Scenario assumptions for fertiliser sector

	Current Policy Scenario	Net Zero Scenario
Specific Energy Consumption SEC	Average efficiency improves to reach India's best available technology with 0.4% improvement per year till 2070	Average efficiency improves to 0.6% every year till it reaches the CPS, 2070 value and saturates after this.

	Current Policy Scenario	Net Zero Scenario
Green Hydrogen	Uptake remains limited until after 2040, when green hydrogen becomes commercially viable, and deployment accelerates to 70% by 2070.	Penetration rises to near 90% by 2070 with strong uptake from 2030, enabling near complete low-carbon transition of ammonia production.
Electricity Supply	Captive generation continues to provide around 70% of electricity consumption in 2070 (same as in 2025). However, within captive, from dominantly fossil in 2025, there will be a gradual shift towards non-fossil fuels, whose share increases to 60% by 2070.	Captive generation continues to provide around 70% of electricity consumption in 2070 (same as in 2025). However, the entire captive power will be a non-fossil-based electricity system by 2070.

Results

Energy Demand: The fertiliser sector's final energy demand will grow substantially with higher production, but the scenarios diverge in magnitude. Under the Current Policy Scenario (CPS), total final energy consumption by fertiliser would rise from 19 Mtoe in 2025 to about 25 Mtoe (treating green hydrogen and captive electricity consumption as part of fuel rather than energy required to generate them) in 2070 (Figure 3.29). This 1.3 times increase would be driven by expansion of output, but partially offset by incremental efficiency gains.

Under the Net Zero Scenario (NZS), energy demand in 2070 would be lower due to higher green hydrogen penetration, which replaces the natural gas required to generate gey hydrogen, reaching around 23.5 Mtoe in 2070. Simultaneously, the share of grid electricity would increase while captive electricity generation would shift from coal to renewables, aligning with the Net Zero trajectory.

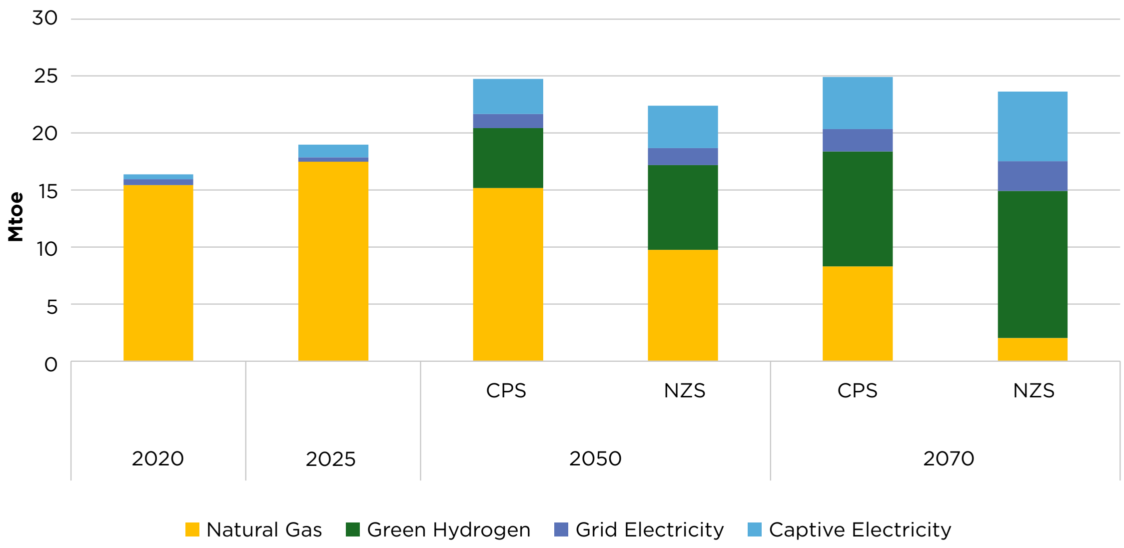

Figure 3.29: Final energy consumption of major fertiliser products (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Emission Intensity

The production of ammonia, the key feedstock for fertilisers, is highly dependent on fossil fuels, resulting in significant CO_2 emissions from hydrogen generation and process energy use. In contrast, urea production uniquely utilises CO_2 as a feedstock, making it a partial CO_2 sink within the fertiliser value chain. During urea synthesis, CO_2 reacts with ammonia to form urea, resulting in the utilisation of approximately 0.73 tCO_2/t urea produced (as considered in this study). Considering this sink of CO_2 during the urea production process, the average emission intensity of fertiliser production is estimated at around ~0.56 t CO_2/t of fertiliser production (Figure 3.30).

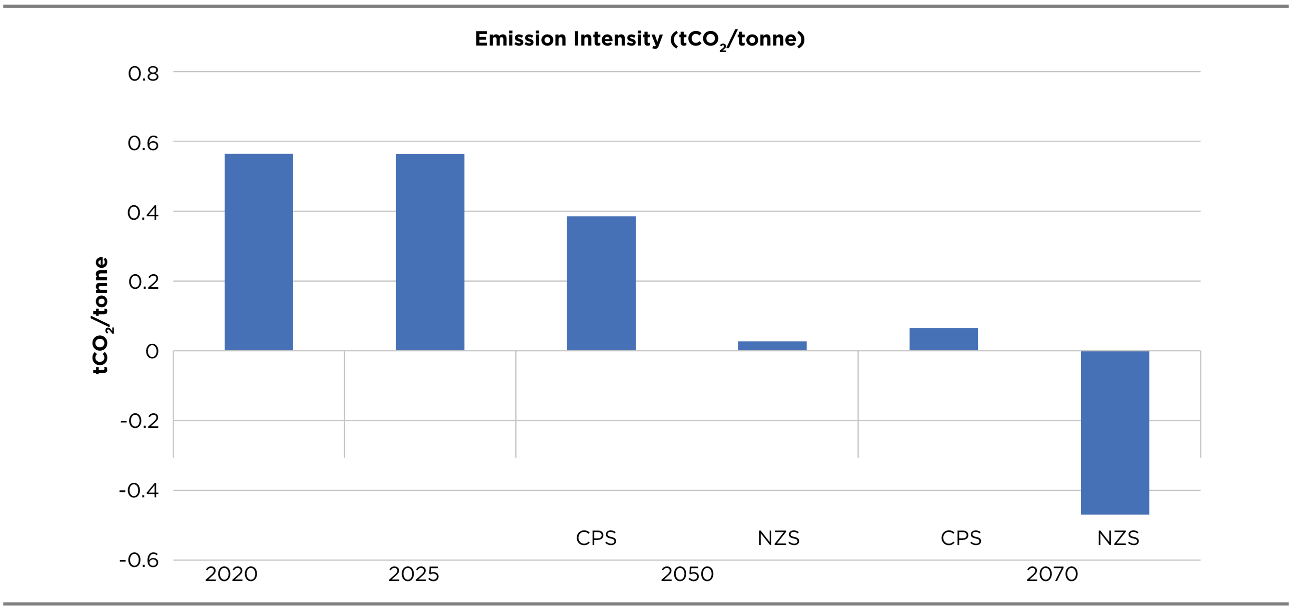

Figure 3.30: Emission intensity of the fertiliser sector (tCO_2/t)

With energy transition and low-carbon transition measures discussed above, emissions intensity would decline over time under both scenarios, although the magnitude of reduction would vary significantly. Under the Current Policy Scenario (CPS), emissions intensity would decrease by about 32% by 2050, driven by incremental efficiency improvements and a gradual shift towards green hydrogen and renewable energy. This reduction would deepen substantially to 88% by 2070, reflecting more widespread adoption of low-carbon technologies and cleaner energy sources.

Under the Net Zero Scenario, grey hydrogen-based ammonia synthesis will be largely replaced by green hydrogen by 2070. This transition would eliminate most process-related CO_2 emissions associated with hydrogen generation, fundamentally altering the carbon profile of the fertiliser sector. Accounting for CO_2 utilised as a feedstock during urea production would mean that the fertiliser production process could shift to a net sink. With the continued incorporation of CO_2 in urea synthesis, combined with near-zero-emission hydrogen and cleaner energy inputs, fertiliser manufacturing could play a carbon-absorbing role within industrial systems, highlighting its potential contribution to long-term Net Zero pathways.

Barriers and Enablers for Fertiliser Sector Energy Transition

Challenges

a. **High import dependence of raw materials:** India currently imports all of the muriate of potash (MOP), 90% of phosphate, and 25% of urea demand (Randive et al., 2022)

b. **Low efficiency of plants:** The average technical efficiency of fertiliser plants stands at 57%, hinting at a significant scope for improvement (Khan, 2017). Energy intensity in some fertiliser production plants is very high (12.6-12.7 Gcal/t of urea) compared with the norm of 5.5 Gcal/Mt of urea (Oak, 2022).

c. **Disproportionate nutrient use:** Despite the NBS (Nutrient-Based Subsidy) policy, which aimed to promote more phosphorus and potassium-based fertilisers, the ratio of Nitrogen:Phosphorus: Potassium (NPK) was 10.9:4.4:1, compared to a consensus that this ratio should be 4:2:1 (The Fertiliser Association of India, 2024).

d. **Low investment in research and development (R&D):** R&D spending in the industry is less than 1% of the total revenue. This hampers innovation and technological advancement in the industry (Khan, 2017).

e. **High production costs:** Production costs are 8-17% higher than the conventional method, depending on the use of urea (Kothadiya et al 2024).

Suggestions

a. **Increase energy efficiency of plants:** Incentivising retrofitting of older fertiliser plants to reduce energy intensity to the level of industry best of 5.5 Gcal/t of urea (Oak, 2022), measures include installing Variable Frequency Drives (VFDs) on pumps and motors, and replacing ageing pumps and compressors. A good example is that of Iran, where older compressor rotors were replaced with high-solidity diffusers, boosting efficiency from 67% to 74%. Similarly, the fertiliser plant's refrigeration cycle was retrofitted by application of a Pinch heat, reducing shaft work by 15% (Panjeshahi, 2008).

b. **Reduce fertiliser imports:** The Indian government has already undertaken many new initiatives to reduce reliance on fertiliser imports. In 2023, the government classified potash and potassic minerals like glauconite as critical (PIB, 2023). This move will bring in private investment through the Mines and Minerals Act. This year, the first mining block of potash and halite was auctioned in India in Rajasthan. Further research is ongoing on alternative sources for NPK that are available domestically and can be utilised (Ministry of Chemicals and Fertilisers, 2022). One of these is Potash Derived from Molasses (PDM), which is a byproduct of the sugar industry that has been included in the NBS policy since 2022.

3.2.9 Refineries

Demand Projections

In India, petroleum products are primarily used in the transport sector, followed by industry, cooking (residential and commercial), agriculture, and power. Transport fuels like diesel and petrol dominate consumption; these two products together account for around 43% of total petroleum product demand.

The model estimates future refinery capacity demand by aggregating projected requirements across sectors under different scenarios. These scenarios are shaped by the specific transition pathways of each sector: shifts to alternative fuels/technologies, efficiency improvements, material re-cycling and policy-driven low-carbon transition. This results in comprehensive projections for conservative as well as ambitious energy transition contexts. Refinery capacities are calculated based on the ratio of crude oil to petroleum products. The total petroleum demand reaches around 400 Mt in 2050 and 345 Mt in 2070 under Current Policy Scenario (CPS) and 290 Mt in 2050 and 150 Mt in 2070 under Net Zero Scenario (NZS) (57% lower than CPS in 2070). Therefore, the crude oil processed will also be lower in NZS as compared to CPS.

Scenario Assumptions

Two scenarios are examined for the Refinery sector: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS), with differences explained in the table below:

Table 3.9: Scenario assumptions for refineries sector

	Current Policy Scenario	Net Zero Scenario
Green Hydrogen	Major driver for Green H_2 with penetration reaching 70% by 2070.	Major driver for Green H_2 with penetration reaching 100% by 2070.
Electricity Supply	Captive generation continues to provide around 90% of electricity consumption in 2070 (same as in 2025). Further, within captive, from dominantly fossil in 2025, there will be gradual shift towards non-fossil whose share increases to 30% by 2070.	Dependence on captive generation decreases to 70% of total electricity consumption in 2070 (Reduced from 90%). The entire captive power will be non-fossil-based electricity system by 2070.

Results:

Total final energy consumption in the refinery sector would increase steadily in the near to medium term, driven by rising crude throughput and increasing refining depth. Until mid-century, energy demand would be dominated by natural gas and petroleum products, supplemented by grid electricity and refinery-derived fuels such as syngas and purge gas. By mid-century, however, significant uptake of green hydrogen would cause a noticeable reduction in the use of natural gas as feedstock for grey hydrogen. A greater shift towards grid-based electricity and progressive low-carbon transition of captive power generation through RE integration would result in a gradual transformation of the refinery energy mix (Figure 3.31).

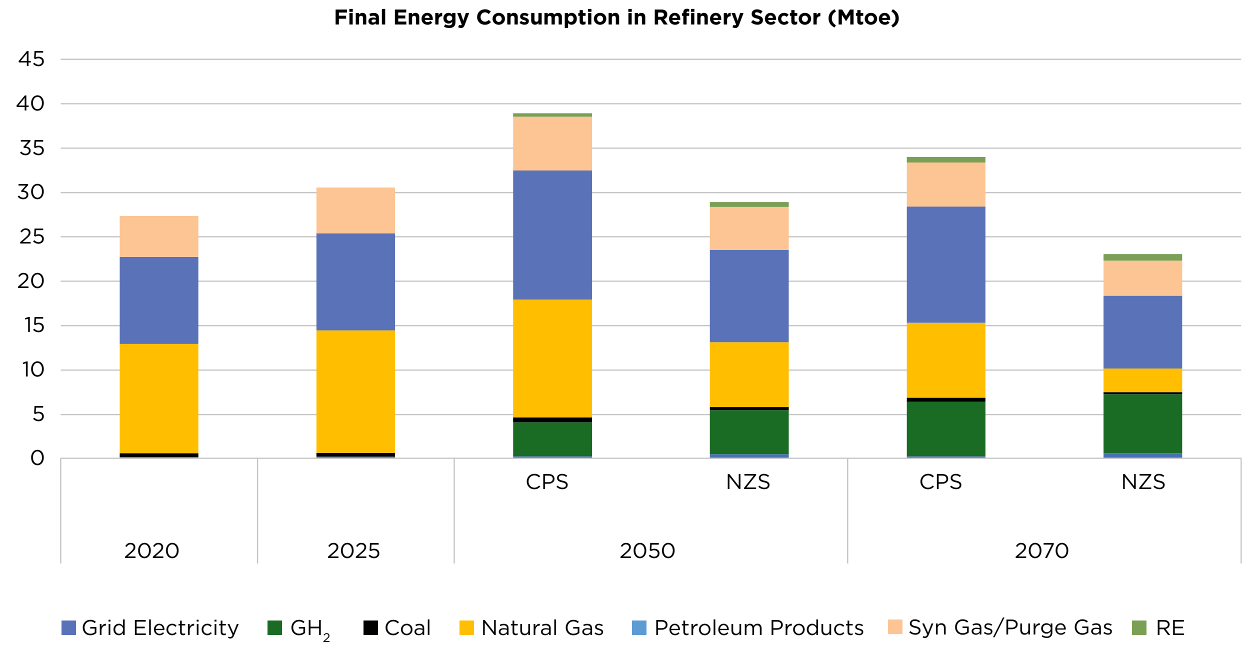

Figure 3.31: Final energy consumption in refinery (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Under the Current Policy Scenario (CPS), despite the growing role of green hydrogen by mid-century, the sector would rely substantially on fossil fuels for thermal energy and captive power. With the increasing demand for petroleum products (rising by 1.6 times in 2050 from 2025 value), total final energy consumption would rise from around 30.5 Mtoe in 2025 to approximately 39 Mtoe by 2050. Beyond 2050, energy demand would decrease slightly (due to a decrease in petroleum product demand from end-use sectors) to about 34 Mtoe by 2070. It should be noted that energy demand estimates do not include the renewable electricity required for green hydrogen production, which lies outside the refinery's final energy consumption boundary.

In contrast, under the Net Zero Scenario (NZS), the impact of significant mid-century green hydrogen deployment would be more pronounced and be complemented by bigger structural changes. Total final energy consumption would decline substantially by 2070, driven by: (i) reduced crude oil demand as petroleum product use, particularly in the energy sectors, falls under the Net Zero pathway, and (ii) a decisive shift in the energy mix towards electricity and green hydrogen, with a corresponding reduction in natural gas and petroleum products. Refinery fuel gas and syngas consumption would also decline as grey hydrogen production is phased out. Total final energy consumption under NZS at 23 Mtoe in 2070, would be 32% lower than that under the Current Policy Scenario (CPS).

Overall, the projection underscores that while refinery energy demand would rise under the CPS, a Net Zero pathway supported by a significant reduction in petroleum product demand and higher green hydrogen penetration would align the sector with long-term low-carbon transition objectives due to moderation in energy demand and a fundamental shift in the fuel mix away from fossil fuels.

Emissions

In the refinery sector, nearly one-third of total emissions are generated by process-related sources, primarily due to the use of grey hydrogen and fossil fuel combustion in catalytic cracking units. The remaining emissions are largely attributable to fossil-fuel-based thermal energy and captive electricity generation, which together account for the bulk of energy-related emissions. The resulting emission intensity of the sector in 2025 is estimated at around 0.28 tCO_2 per tonne of crude oil processed (Figure 3.32).

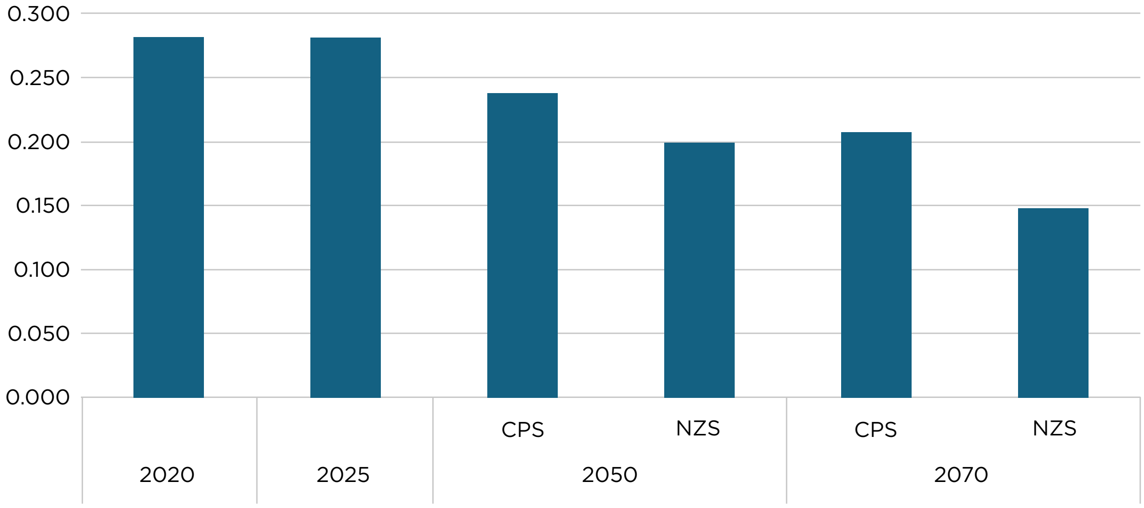

Figure 3.32: Emission intensity of refinery sector (tCO_2/t) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Despite the implementation of low-carbon transition measures such as energy-efficiency improvements, fuel-switching and green hydrogen penetration defined under the Current Policy Scenario (CPS) trajectory, the refinery sector continues to retain a significant emissions footprint. Under the CPS, emission intensity would decline modestly by about 26%, reaching approximately 0.20 tCO_2 per tonne, reflecting the limited abatement potential for process emissions and the continued reliance on fossil fuels. In contrast, deeper low-carbon transition measures deployed under the Net Zero Scenario (NZS), including use of renewable energy, cleaner fuels, and large-scale penetration of green hydrogen, would reduce emission intensity to around 0.145 tCO_2 per tonne of crude oil processed in 2070, corresponding to an overall reduction of approximately 47% relative to 2025 levels. For unabated emissions, adoption of carbon capture, utilisation, and storage (CCUS) would be crucial. CCUS will play a critical role with captured CO_2 assumed to be partially utilised in enhanced oil recovery (EOR).

Barriers and Enablers for Refinery Sector Energy Transition

Challenges

a. **High CO_2 from Steam Methane Reforming (SMR) process:** Hydrogen utilised for hydrocracking and desulfurisation generates a significant amount of emissions (9 $kgCO_2/kg\ H_2$), if produced using the Steam Methane Reforming (SMR) process (Sun & Elgowainy, 2019).

b. **Barriers to CCUS and renewable integration:** Retrofitting refineries to incorporate CCUS or RE is expensive and involves large investments. In addition, a lot of Indian refineries operate on old infrastructure that is not suitable for CCS or RE integration.

c. **Ageing equipment and limited digital controls:** This results in energy intensity above world best practices and limits the scope for optimisation in older plants. Further, lack of predictive maintenance and advanced analytics leads to unplanned outages, flaring and inefficiencies, thereby increasing carbon intensity.

Suggestions

a. **Improving energy efficiency:** Installing heat recovery systems, upgrading reactor internals, shifting from steam to electric drivers and using advanced process controls would help lower energy use and improve reliability.

b. **Invest in modular CCUS:** Modular CCUS units allow phased installation, reducing upfront risk, shutdowns, and retrofit challenges. IOCL's Koyali refinery reports capture costs of USD 55–60/tCO_2, with potential applications in oil fields, chemical production, or carbon credits to offset investment (Sharma et al., 2025). The REALISE CCUS programme in the EU, China, and South Korea aims to double capture rates, cut costs by nearly a third, and lower emissions by 10 Mt a year by 2030.

c. **Adopting advanced catalysts:** new generations of catalysts, operating at lower pressures and temperatures, reduce hydrogen requirement for desulfurisation, resulting in lower energy consumption.

d. **Invest in heat recovery and residual heat use:** Refineries can capture and reuse waste heat from flue gases, reducing both cost and emissions (e.g., Reliance's Jamnagar refinery in India). Shell's Pernis refinery in Rotterdam began supplying residual heat to a local network in 2018, providing heating for over 16,000 homes and reducing CO_2 emissions by 35,000 tonnes annually (Shell 2019).

e. **Diversification into low-carbon products:** Refineries can co-process renewable feedstocks in existing hydrotreaters to produce renewable diesel or sustainable aviation fuel (SAF). In many cases, with adequate hydrogen supply, only a catalyst change is needed in kerosene hydrotreaters, allowing up to 5% renewable blending at relatively low cost (Chopra 2024).

3.3 OVERALL INDUSTRY RESULTS AND SUMMARY

India's industry sector consumed about 302 Mtoe of energy in 2020 and 369 Mtoe in 2025[10], with the mix dominated by fossil fuels. In the fuel mix for 2020, coal supplied roughly 34% of energy demand, followed by petroleum products (37%), natural gas (12%), electricity (15%), and 1% biomass. Within this, a sizeable fraction of fuels is used as feedstock rather than for combustion, e.g. naphtha/natural gas in chemicals and petrochemicals and natural gas in ammonia/urea, creating process-related emission profiles distinct from those of fuel use.

Captive power contributes about 41% of total industrial electricity consumption, which is generated predominantly from coal (around 86% of captive output). Gas and diesel constitute about 11%, and hydro, solar and wind together account for just over 3% of captive electricity.

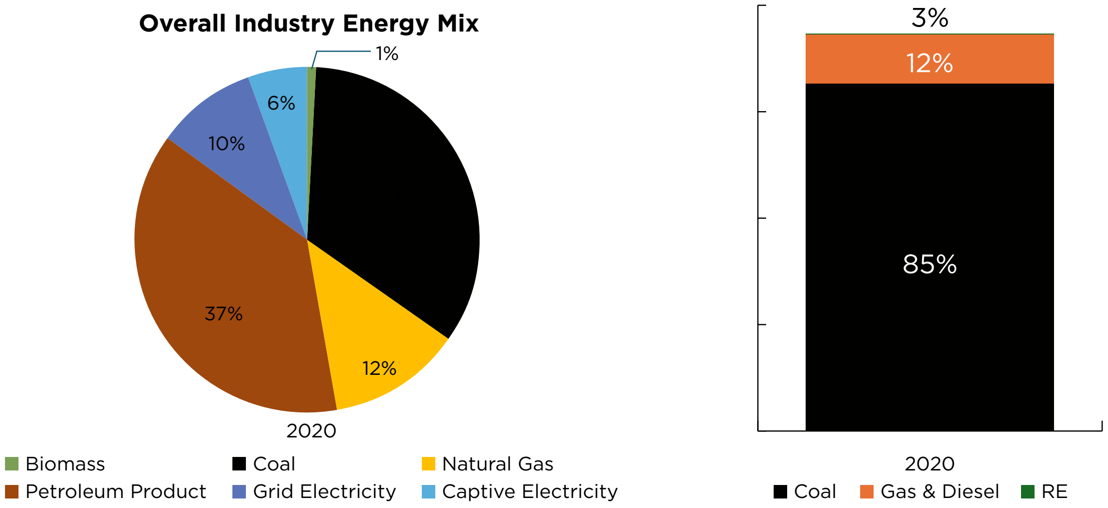

Figure 3.33: Overall industrial energy supply mix and fuel type for captive electricity, 2020

Energy Demand Projections

Final energy demand. In Current Policy Scenario (CPS), final energy demand increases from 370 Mtoe in 2025 to 980 Mtoe in 2050 and 1150 Mtoe by 2070. Fossil share of final energy moderately declines from 83% in 2025 to 72% by 2050 and 61% by 2070, with corresponding increase shifting towards electricity whose share rises from 16% in 2025 to 24% by 2050 and 29% by 2070. Coal continues to play a dominant role till 2050, whose share in final energy increases from 39% in 2025 to 45% by 2050 before declining to 35% by 2070. Biomass plays a limited role in CPS, with a modest increase from 1% in 2025 to 5% by 2070 in final energy.

In Net Zero Scenario (NZS), on the other hand, final energy increases to 890 Mtoe by 2050 (~10% lower compared to CPS) and 980 Mtoe by 2070 (15% lower compared to CPS). The share of fossil declines 52% by 2050 and 26% by 2070 from a predominantly fossil system in 2070. Coal share drops to 7% by 2070, with majority of coal-use operating with Carbon Capture in NZS. Electrification continues to play a major role, with share increasing to 37% by 2050 and

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[10] This includes fuels for non-energy uses, as well as consumption categorised under the "non-specified" category and statistical differences in the MoSPI energy balance, which are assumed to be captured within the "Other Industries" category, after accounting for transport sector allocations.

55% by 2070. In practice, this entails deep electrification of low and medium temperature heat, a switch to H_2-based routes for very high temperature and process needs (for example DRI-EAF steel, green ammonia and methanol), and a transition of captive power from fossil units to grid and captive renewable supply. Also, in comparison to Current Policy Scenario (CPS), biomass share also increases to 9% by 2070. Green hydrogen scales from zero today to 50 Mtoe (about 6% of industrial energy) by 2050 and 100 Mtoe (around 10%) by 2070 (See Figure 3.34 and Table 3.10).

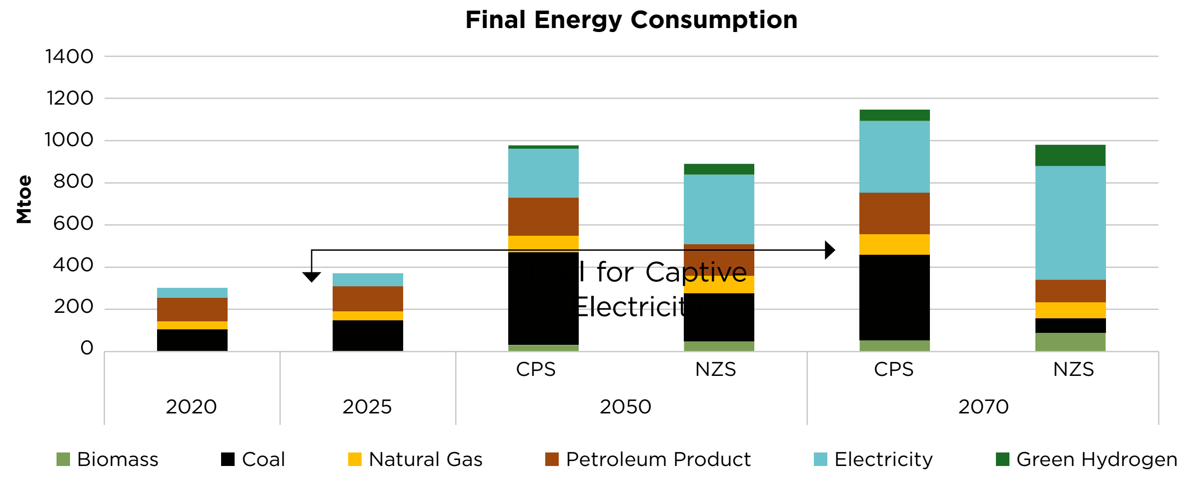

Figure 3.34: Projections of demand (Mtoe) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Table 3.10: Projections of demand breakup under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

	2020	2025	2050		2070	
			Current Policy Scenario	Net Zero Scenario	Current Policy Scenario	Net Zero Scenario
Biomass	1%	1%	3%	5%	5%	9%
Coal	34%	39%	45%	26%	35%	7%
Natural Gas	12%	12%	8%	10%	8%	8%
Petroleum Product	37%	32%	18%	17%	17%	11%
Electricity	15%	16%	24%	37%	29%	55%
GH_2	0%	0%	2%	6%	5%	10%
Total Energy Demand (Mtoe)	302	370	980	890	1150	980

Pillars of Net Zero Transition

India's industrial pathways to Net Zero rests on a portfolio of measures. This section discusses key levers critical for hard-to-abate sectors, including green hydrogen, circular economy, and carbon capture technologies. Sector-specific interventions and potential levers are discussed in detail within each respective sub-sectors.

Green Hydrogen

Hydrogen is the critical decarbonisation vector for hard-to-electrify industrial processes providing a clean reducing agent for ironmaking and a zero-carbon feedstock for ammonia, and refinery uses. From a near-zero green baseline in 2025 (hydrogen use is predominantly grey, concentrated in refineries and fertilisers), the two scenarios project sharply divergent trajectories.

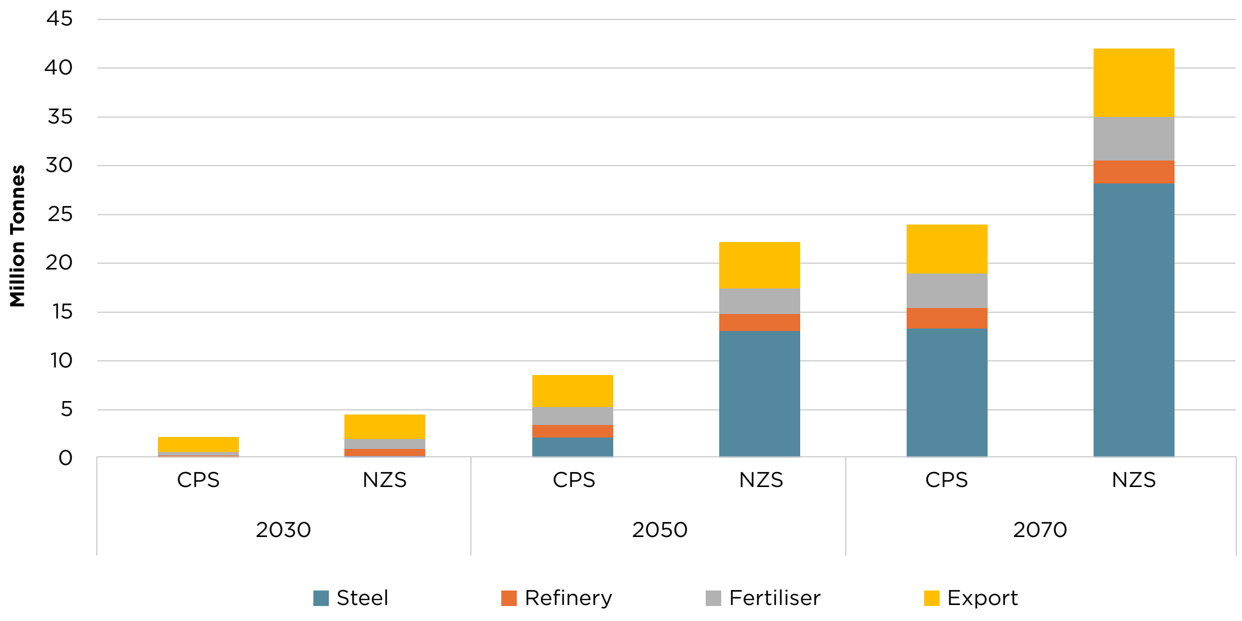

Figure 3.35: Green hydrogen projection in CPS and NZS (million tonnes) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Under the Current Policy Scenario (CPS), green hydrogen would grow mainly as an adjunct to fossil routes: demand reaches 8.4 Mt in 2050, and 24 Mt in 2070. The sectoral pattern shifts gradually toward steel, about 2.0 Mt in 2050 and 13.3 Mt in 2070, with the remainder of 2070 splitting between exports (5 Mt), fertilisers (3.5 Mt), and refineries (2 Mt). In Net Zero Scenario (NZS), green hydrogen becomes a pillar of industry. Demand rises to 22 Mt in 2050, and 42 Mt in 2070, almost double that under CPS. Steel would be the anchor load (13.0 Mt in 2050 and 28.2 Mt in 2070) as hydrogen-DRI/EAF replaces coking-coal routes, fertilisers shift decisively to green hydrogen as feedstock (4.5 Mt), refineries green their process hydrogen even as crude throughput moderates (2.3 Mt), and an export platform in ammonia/synthetic fuels underpins scale (7 Mt) (Figure 3.35).

This has material consequences on power. At around 55 MWh of electricity required per tonne of hydrogen, CPS requires about 470 TWh (2050) and 1330 TWh (2070) for electrolysis, while

Net Zero Scenario (NZS) requires 1,210 TWh (2050) and 2,310 TWh (2070). Green hydrogen thus ties the industrial transition directly to clean-power expansion and long-term power-market reforms (open access, long-tenor PPAs, balancing and storage).

Circular Economy

India starts from a base that is dominated by primary materials— for example, cement remains clinker-intensive, and steel relies heavily on ores and fulfils scrap supply shortfalls through imports (India was the world's second largest ferrous-scrap importer in 2023, bringing in 11.76 Mt, up 40% year on year (S&P Global, 2024).

Circular economy strategies decouple growth from raw-material use by maximising reuse, recycling, and material recovery. Under the Current Policy Scenario (CPS), measures like extended producer responsibility (EPR), end-of-life vehicle (ELV) rules, and improved recycling deliver notable gains. The Net Zero Scenario (NZS) delivers deeper interventions across key sectors. In steel, scrap utilisation is estimated to rise from 22% at present to 30% by 2050 and 40% by 2070, reducing reliance on energy-intensive ore-based smelting. Recycling would become a prominent source of aluminium and use just 5% of the energy required for primary production. In cement, lower clinker ratios (0.6 (CPS) and 0.55 (NZS)) and the adoption of blended cements with recycled aggregates. At an output of 1,958 Mt in 2070, nearly 100 Mt of clinker would be avoided annually through higher use of SCM (slag, calcined clay, pozzolans, limestone). (Figure 3.36)

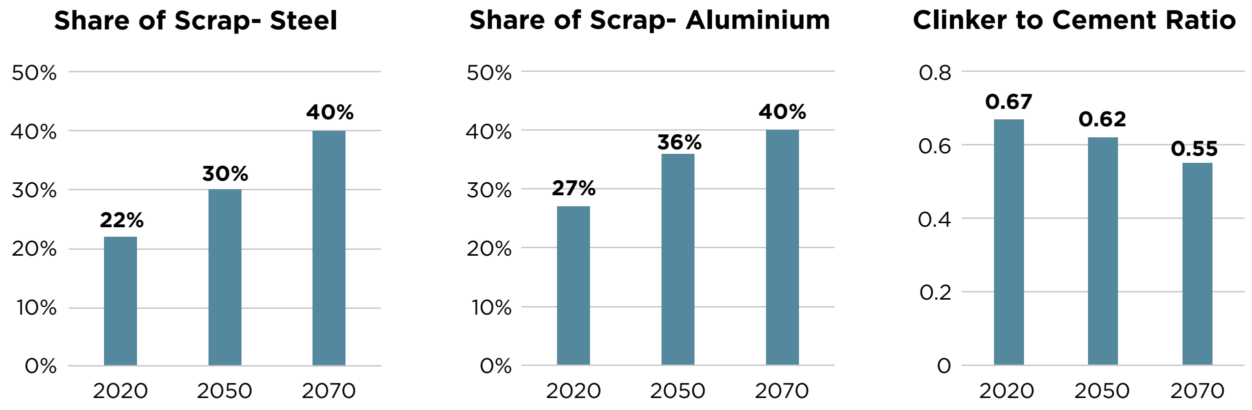

Figure 3.36: Net Zero Scenario - share of scrap in steel and aluminium, and clinker to cement ratio in cement production projections

Carbon Capture

Even after efficiency improvement, electrification, circularity, and green hydrogen, India's industry retains a large "hard" core of process CO_2 (This is from cement calcination, steel off-gases, aluminium anode) and residual fuel/feedstock emissions (Figure 3.37).

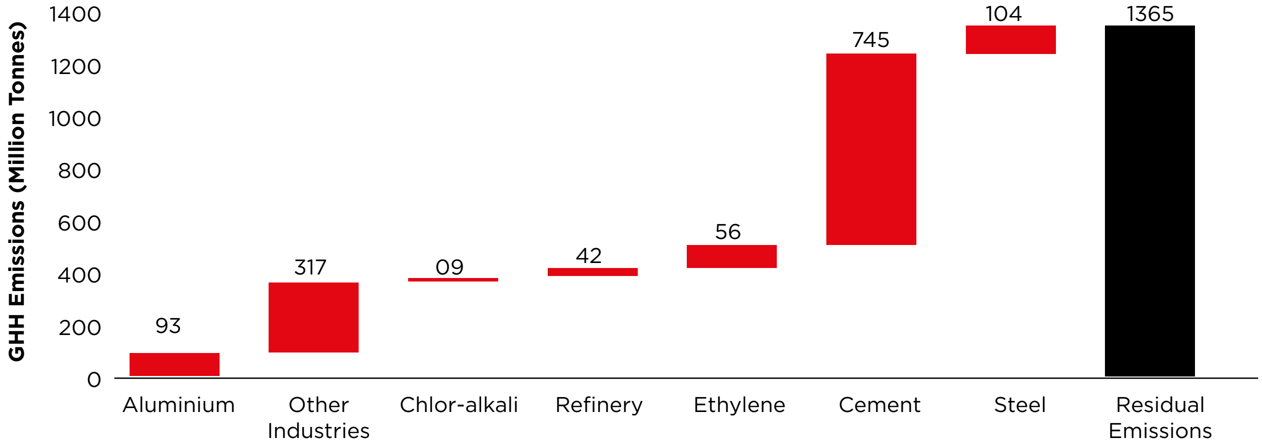

Figure 3.37: Break-up of residual emissions ($MtCO_2$)

Under the Current Policy Scenario (CPS), no CCUS is installed, so these emissions remain unabated. In the NZS, capture scales as the last-mile lever: rising from pilot volumes in the 2030s to around 100 $MtCO_2$/yr in 2050, then expanding with CO_2 hubs, pipelines, and saline storage to roughly 1,000 $MtCO_2$/yr in 2070, covering essentially all point-source-amenable residuals.

Investment Requirement

India's industrial low-carbon transition will demand huge capital to finance the shift from conventional fossil assets to large-scale deployment of electrification, hydrogen, and carbon capture systems, which are capital-intensive. Financing clearly needs to prioritise efforts towards electrification, efficiency and first-of-a-kind hydrogen projects till 2060, while the post-2050 period is dominated by carbon capture and the build-out of hydrogen and CO_2 networks. By 2070, under the Net Zero Scenario, the industry sector alone will require cumulative investments of around USD 6.1 trillion, of which roughly USD 2.2 trillion is needed before 2050 and another USD 3.9 trillion after 2050 (Figure 3.38). The investment profile is back-loaded, with nearly two-thirds occurring after mid-century as carbon capture and hydrogen infrastructure expand.

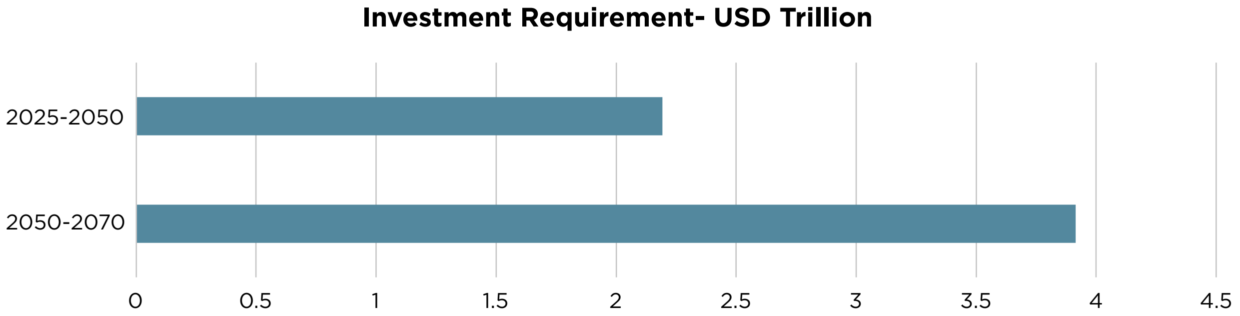

Figure 3.38: Total investment requirement (USD Trillion)

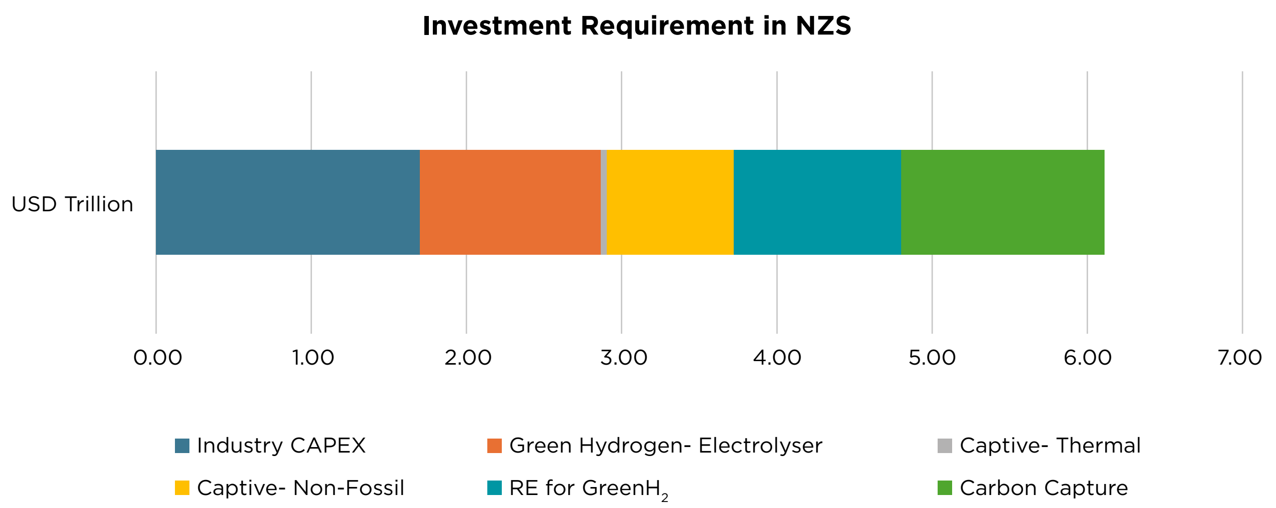

Figure 3.39: Technology-wise Investment requirement in NZS (USD Trillion)

- **Green Hydrogen and its Renewable Backbone (36%):** About USD 1.2 trillion in electrolysers and USD 1.1 trillion in dedicated renewables, front-loaded through the 2030s–40s and then accelerating post-2050 as hydrogen becomes a mainstream fuel and feedstock.
- **Captive Electricity (13%):** investments would be made mainly before 2050 as firms hedge reliability and cost while moving off captive coal and gas (captive investments in thermal USD 0.04 trillion and nuclear USD 0.02 trillion would remain marginal).
- **Carbon Capture Technologies (21%):** Minimal before 2050 but surging thereafter to abate residual process CO_2 in cement, steel, and chemicals.
- **CAPEX for Industry Expansion (30%):** The remainder investments would finance core plant transformation: steel (12%) from BF-BOF toward H_2-DRI/EAF supported by scrap-EAF, cement (5%) for kiln efficiency, waste-heat recovery, and lower-clinker routes, with capture equipment counted under CCUS, chemicals (7%) toward gas- and then hydrogen-integrated feedstocks with CCUS on residual fossil routes. Another USD 0.30 trillion is distributed across aluminium, paper, textiles, fertilisers, chlor-alkali, and refining for capacity expansion (Figure 3.39).

In comparison, Current Policy Scenario (CPS) finance requirements are nearly half those under Net Zero Scenario (NZS), at USD 3.4 trillion by 2070. Under CPS, investment primarily meets incremental demand growth, with around 55% of total finance going to CAPEX by 2070, compared to about 30% under NZS. NZS, by contrast, will require a more ambitious investment strategy focused on a complete transformation of the industry sector through accelerated deployment of GH_2, RE RTC, advanced captive nuclear, and CCS.

Limitations and Future Scope

Sectoral Coverage: The current framework disaggregates industries into nine PAT (Perform, Achieve, and Trade) sectors and a residual "Other Industries" sub-sector. While the nine PAT industries are modelled in detail, covering specific technologies, their specific energy consumption (SEC), fuel mixes, and investments, the "Other Industries" category lacks technology-specific data. For the estimated energy consumption in the other industries category crude methodology is adopted. For the base year, the fuel mix in "Other Industries" is estimated based on residual fuel allocated after accounting for other sectors, from which energy consumption per unit of Other Industries Gross Value Added (GVA) is derived. For future projections, total fuel consumption for this sub-sector is estimated using projected GVA, while accounting for energy efficiency improvements and fuel switching toward cleaner fuels and electricity.

Technology Cost Trends: Cost trends for emerging technologies such as green hydrogen electrolysers, CCUS (Carbon Capture, Utilisation, and Storage), and LC3 cement are derived based on current best knowledge and stakeholder consultations. However, these estimates may vary significantly in the future as markets evolve and economies shift due to factors like scale-up effects, policy incentives, and supply chain maturation. Industry sector modelling thus faces limitations in projecting long-term investment needs accurately.

Investment Required for Energy Efficiency Measures: In this study, detailed energy efficiency improvements in a specific sector, identified via industry stakeholder consultations, are accounted for to estimate future Specific Energy Consumption (SEC). However, the related capital investments required for these measures are not explicitly modelled.

Stranded Assets Non-Accountability: With the transition in industry sectors, particularly under Net Zero scenarios, certain assets may become stranded, including their capacity and associated costs. This study does not account for such stranded assets or their economic implications.

Exclusion of Non-Fuel Raw Materials: This analysis accounts exclusively for fuel inputs in terms of energy consumption and non-energy applications in different industries. Non-fuel raw materials, such as iron ore for steel production, bauxite/alumina for aluminium smelting, and limestone for cement clinker, are excluded from the modelling framework. Consequently, their supply chain constraints, resource availability, procurement costs, and price volatility are not incorporated into capacity expansion, cost projections, or scenario pathways.

Aggregation of Sunrise Industries in Other Industries Category: Sunrise industries, such as solar cell manufacturing, wind turbine production, and electrolyser fabrication, will exhibit significant energy consumption as domestic manufacturing scales up in India. These sectors are captured within the aggregate "Other Industries" category, with demand projections derived from GVA growth excluding PAT sectors. However, their distinct technology profiles, rapid capacity expansions, and specialised energy intensity characteristics are not explicitly disaggregated or modelled separately from the broader category.

Uniform Capacity Utilisation Assumptions: This study assumes a constant 80% Plant Load Factor (PLF) across all industrial capacities to estimate investment requirements. In reality, PLF varies significantly across industry categories, technologies, and historical periods due to demand fluctuations, policy interventions, and operational efficiencies. This uniform assumption introduces uncertainty in capacity expansion projections and associated capital expenditure estimates.

Scrap Availability and Supply Constraints: For scrap utilisation scenarios, this analysis assumes full availability of required scrap inputs without supply-side constraints. Detailed modelling of scrap generation, collection logistics, quality specifications, import dependencies, or domestic recycling capacity expansions has not been conducted.

Exclusion of Non-CO_2 and PFC Gas Abatement: This analysis does not model abatement measures for non-CO_2 greenhouse gases or perfluorocarbons (PFCs) emitted by industrial processes. Consequently, their mitigation potentials, technology costs, and emission reduction contributions are excluded from Net Zero scenario projections.

Future Model Improvements

Future iterations of the industry sector modelling framework will address these limitations through enhanced data granularity and dynamic methodologies. Key enhancements include disaggregating "Other Industries" into technology-specific sub-sectors (including sunrise industries), incorporating non-fuel raw material supply chains and scrap recycling dynamics, explicitly modelling energy efficiency capital requirements alongside abatement costs for non-CO_2/PFC gases, and integrating stranded asset risk assessments under varying Net Zero transition pathways. These improvements would enable more robust investment projections, reduce uncertainty in cost trajectories for emerging technologies, and better align with India's comprehensive energy transition and Viksit Bharat objectives.

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4

CHALLENGES AND SUGGESTIONS

Challenges and Suggestions

4

India stands at a defining moment where it aspires to become a developed economy while also ensuring that the transition to developed status is through sustainable means. As the engine of the 'Viksit Bharat 2047' vision, the industrial sector drives economic resilience, infrastructure growth, and employment and yet, it remains the hard-to-abate component of the Net Zero journey, accounting for ~24% of national emissions in 2020 (MoEFCC, 2024). Decoupling industrial growth from carbon intensity is no longer a choice but a competitive necessity. This transition rests on four structural pillars: Energy Efficiency, Circularity, Electrification, and Clean Fuels & Technologies, supported by an enabling ecosystem of finance and skilled labour. The following chapter discusses key challenges within these pillars and outlines measures for enabling low-carbon transition in industrial sectors.

4.1 IMPROVING ENERGY EFFICIENCY

Around two-thirds of global energy is wasted (World Bank 2025). Therefore, energy efficiency is fundamental to low-carbon transition and the IEA labels it the "first fuel" (IEA, 2024). However, global energy efficiency improved by just 1% in 2024 (Guy et al. 2025). India has 5.93 crore registered MSMEs, while they contribute substantially to value addition and employment, many use outdated, inefficient technologies and processes (PIB 2025). Even a modest 1.3% annual improvement could avoid nearly 4,606 million tonnes of CO_2e emissions between 2020 and 2050 (Dayal et al. 2025). Recognising the benefits of energy efficiency, India launched its Perform, Achieve and Trade (PAT) scheme in 2012. Its market-based energy efficiency approach, covering 1,333 designated entities across 13 energy-intensive sectors, has enabled savings of nearly 8% in the annual energy use of these sectors (Ministry of Power 2024). Yet, Indian industries today face multiple challenges in improving energy efficiency.

Table 4.1: Challenges and suggestions for improving energy efficiency

	Key Barriers	Intervention/ Suggestion
Energy Performance Monitoring	**Weak performance monitoring** Lack of real-time monitoring leads to reactive maintenance (Bansal & Tilottma, 2024). The 3-year audit cycle under PAT (BEE 2014) is too infrequent to optimise performance. **Lack of Benchmarks:** Absence of uniform benchmarks for complex thermal processes across diverse sectors.	**Facilitate continuous performance monitoring.** Shift from infrequent audits to continuous digital verification, leveraging IoT and AI tools and standardising the monitoring by adopting ISO 50001 standards. **Strengthen the Indian energy efficiency portal of BEE** to include global and India benchmarking data sector-wise.
Financing and Technology Modernisation	**Limited access to affordable finance** MSMEs (e.g., textile, foundry clusters) operate on thin margins and lack capital for upgrades despite 1–5-year payback on many of these technologies. Lending costs are also high for MSMEs due to weak balance sheets and reliance on informal credit. **Prevalence of outdated technologies** Prevalence of obsolete technologies like inefficient motors and small coal-fired boilers due to limited access to finance and a lack of awareness Significantly high-grade heat (Steel/Cement) and low-grade heat (Textile/Paper) are vented out instead of being recovered or reused. Process heating <150°C relies heavily on fossil fuels.	**Effective implementation and scaling of the newly launched ADEETIE scheme** (Assistance in Deploying Energy Efficient Technologies in Industries & Establishments) through interest subvention and end-to-end project management support, addressing financial and awareness bottlenecks **Reducing the burden on MSME balance sheets through ESCO models roll-out** Scale the ESCO model where it invests in the upgrade (e.g., swapping old motors for IE3/IE4 standard motors) and recovers costs from shared energy savings. **Considering Waste Heat Recovery** as RE for the purpose of Renewable Consumption Obligations (RCOs) **Promote adoption of Heat Pumps** for catering to low-heat applications through VGF mechanisms till the Total Cost of Ownership viability is achieved.

4.2 BUILDING CIRCULARITY IN MANUFACTURING

The strong reliance on virgin materials is one of the key challenges of industrial decarbonisation in India, leading to high resource depletion, carbon emissions, and significant waste generation. For instance, in textiles, only 34% of waste is reused, and 25% is recycled into yarn, resulting in high dependency on virgin fibres, driving emissions and resource stress (CSTEP and GIZ 2025). In the pulp and paper sector, large mills generate 168–282 m^3 of wastewater per tonne of paper, while smaller mills discharge even more at 187–338 m^3 per tonne, mainly due to a lack of efficient chemical recovery systems, which otherwise could be internally recirculated and reused (Pathe and Nandy 2021). Similarly, each tonne of scrap in the steel industry saves 1.1 tonnes of iron ore, 630 kg of coking coal, and 55 kg of limestone (Ministry of Steel, 2024).

A circular economy is key for low-carbon transition, as closing material loops can deliver both economic and environmental benefits, making industries competitive and more resilient in the long run. For example, in the steel sector, every tonne of scrap used reduces emissions by 58%, cuts water consumption by 40% and generates 97% less mining waste in comparison to primary steelmaking (G20 Secretariat India, CEEW, RMI, and WRI India 2023). With India's growing demand for infrastructure and real estate, increasing the share of scrap in production can ease pressure on natural resources while reducing the carbon footprint. The economic opportunity from circularity is equally significant. India's circular economy is expected to be worth nearly USD 2 trillion and create close to 10 million jobs by 2050, creating new channels for innovation, startups, and recycled product developers (MoEFCC 2025).

Table 4.2: Challenges and suggestions for building circularity in manufacturing

	Key Barriers	Suggestion & Intervention
Creating Demand for Circularity	**Low quality of recycled materials** Recycling and resource recovery (metal scrap, wastepaper, textiles, plastics) are largely handled by informal actors, resulting in variable quality, weak traceability, and often leading to downcycling. Informal sector bypasses safety and other standards, making formal recycling less competitive. Lack of standardised grading and certification for secondary materials creates low market confidence. Buyers are hesitant to pay premiums for "eco-labelled" or recycled-content products due to quality risks. **Feedstock Inconsistency:** Industrial users require uniform quality feedstock. However, mixed waste streams and a lack of pre-processing infrastructure lead to inconsistent moisture and calorific values, causing process instability.	**BIS to introduce rigorous grading and quality standards** for secondary materials to create assured demand **Notify Green Public Procurement (GPP)** norms, which will incentivise use of BIS-labelled recycled material. **Provide additional incentives** under PLI like scheme coverage for utilizing domestically recycled materials. **Provide one-time waiver** of outstanding liability and registration fees to informal operators, enabling them to overcome initial compliance barrier for integration into formal sector. **Introduction of minimum recycled content** guidelines for key sectors **Enable traceability by promoting Digital Product Passports,** which will contain recycled information to nudge consumer behaviour **Expand EPR to include** additional high-impact and currently under-regulated product streams such as textiles, footwear, batteries, etc., and strengthen monitoring for effective implementation of EPR.
Import Dependency on Scrap	**Limited domestic scrap** Domestic recovery remains inadequate, forcing heavy reliance on imported scrap (Steel, Aluminium, Paper)[17], exposing industry to global price volatility and supply shocks.	**Promote domestic recycling industry** through strong demand signals and assured offtake. **Rationalise GST and import duties** to favour scrap recycling.

	Key Barriers	Suggestion & Intervention
Import Dependency on Scrap	Many developed countries are restricting scrap exports for promoting domestic low-carbon transition e.g. EU proposed a scrap ban on plastic and non-hazardous waste (like metals, paper) to non-OECD nations, starting from 2026 and 2027, respectively. Similarly, China and Russia have imposed export restrictions, tightening global scrap availability. **Fiscal policy distortions** Inverted duty structures (e.g., higher duties on scrap imports than finished products in some segments) discourage domestic recycling value addition.	**Launch organised scrap auctions** and index-linked pricing to reduce volatility. **Strengthen adoption of waste pre-treatment, and advanced sorting** (shredders, zorba, optical sorters) technologies.
Waste Management	**Logistical Fragmentation:** Supply chains for waste-to-resource streams (biomass, MSW, industrial by-products) are fragmented and expensive. Moving waste from generation points (cities/farms) to utilisation points (industrial hubs) often incurs high transport costs that outweigh the material value. This often also results in weak industrial symbiosis. **Multiple layers of approval** India's current waste regulatory framework requires multiple layers of authorisations and approvals, including environmental consents, hazardous waste permits, and EPR registrations. **Import reliance on waste processing equipment** Huge import dependency in manufacturing of waste processing equipment, with limited domestic contribution	**Assure offtake** through setting up of aggregation platforms which can be private-led, or public-private partnerships. **Provide details of collection sectors and consumer-facing platforms** on central and state government websites, targeted advertisements in newspapers and digital media. **Promote "waste exchange" clusters, whereby** by-products of one industry (e.g., slag, sludge, heat) become inputs for another. **Establish decentralised pre-processing centres** (drying/shredding/baling) near waste sources to densify materials, reduce transport costs, and ensure consistent quality for industrial users. **Promote common sorting and pre-processing infrastructure in MSME clusters** through PPP model. **Unified waste management license** enabled through a digital single-window system with time-bound approvals. **National Manufacturing Mission** may include domestic manufacturing of waste processing equipment as a priority sector. **Integrate informal workers into EPR chains** via verified IDs, training and PPE. **Develop awareness and capacity-building programs** to enable waste processing and recycling companies to participate effectively in voluntary carbon markets.

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[17] India imported nearly 11.7 million tonnes of ferrous scrap in 2023 to meet its manufacturing requirements, 40% higher than the quantity imported in 2022

4.3 ELECTRIFICATION OF INDUSTRIAL ENERGY DEMAND

Industrial electrification is emerging globally as a key lever for decarbonising manufacturing by replacing fossil-fuel based heat and processes with electric alternatives like heat pumps, boilers, and furnaces. In India, advancing this transition would not only cut emissions but also strengthen global competitiveness as supply chains and markets shift toward low-carbon production. As of 2022, electrification of the industrial sector in India stood at only 16% (NITI Aayog) and needs to rise as the economy transitions to low-carbon alternatives.

Table 4.3: Challenges and suggestions for electrification of industrial energy demand

	Key Barriers	Suggestion & Intervention
Ensuring Affordable and Reliable Electricity	**High cost of electricity** India's power sector is highly regulated, and unlike many countries, India's domestic and agricultural electricity tariffs are more subsidised than industrial and commercial tariffs. This price distortion led to low electrification rates (currently ~16%) in Indian industries. High demand charges and banking limits also make electrification challenging.	**Rationalisation of power tariffs** in the long-term to reflect the true cost of electricity and effective enforcement of Time-of-Day tariffs. **Facilitating timely approvals** for industry seeking **Green Energy Open access** **Promote and scale Renewable Energy Service Company (RESCO) models** that aggregate demand, achieve economies of scale, and offer professional energy management services, reducing the operational burden on individual industries. **PM Surya Ghar-like initaitive for MSMEs:** Introduce targeted rooftop solar scheme for MSMEs providing direct capital subsidies.
	The cost of steam generated using electricity is often higher than that generated using coal or gas, making electric heating uncompetitive without policy support. **Reliability of electricity** Frequent power outages and voltage drops make it difficult for industries to rely solely on grid electricity. Industries need round-the-clock power; even short disruptions cause high production losses, forcing them to rely on captive coal power plants. While solar/wind costs have fallen, industries cannot rely solely on them due to intermittency and a lack of cost-competitive storage options. Open-access approvals face regulatory friction, and grid congestion constrains the reliability of power supply in terms of on-schedule supply certainty and cost predictability.	**Scale implementation of Firm Dispatchable Renewable Energy (FDRE) contracts** through deployment of Hybrid plants matching industrial load profiles. **Develop dedicated power feeders for industrial zones** which can provide assured 24×7 grid power, reducing dependence on self-generation and encouraging industries to shift to cleaner electricity sources.

	Key Barriers	Suggestion & Intervention
Technology Readiness & Financing	**High upfront cost and commercially unviable electrification technologies** While electrification is mature for low-temperature heat (<150°C), technologies for high-temperature process heat (e.g., cement kilns, ethylene crackers) are either nascent or commercially expensive. Transitioning from fossil-fuel boilers to efficient electric alternatives like Industrial Heat Pumps or Electric Boilers requires significant capital investment. MSMEs (e.g., in Textile clusters) lack the financial depth to fund this asset replacement despite the efficiency gains. **Skill shortages** There are limited process design standards for electric heat. Moreover, there is a shortage of skilled Engineering, Procurement, and Construction (EPC) contractors and O&M providers for electrified heat systems (e.g., heat pumps). Factory users perceive risks in adopting these new technologies.	**Develop sector-wide electrification roadmap** linking temperature ranges, processes, and available electrification technologies to guide industries in sequencing their transition (e.g., prioritising low-grade heat <150°C first). **Promote blended finance instruments with assured green premiums for mature electric technologies** such as electric boilers, where high operating costs limit adoption despite technical and cost competitiveness. **The National Manufacturing Mission** may include domestic manufacturing of heat pumps and electricity boilers as a priority sector.

4.4 DEPLOYMENT OF NEW TECHNOLOGIES AND FUELS

Globally, industrial decarbonisation is being driven by a mix of newer innovative technologies, sustainable fuels, and materials. While green hydrogen is being explored for steel, refineries and fertiliser industries, CCUS is emerging as a new technology to capture CO_2 from point sources such as cement factories. Similarly, sustainable materials such as inert anode technology are being developed to replace their conventional counterparts and reduce aluminium industry emissions. The initial transition stages are more focused towards blending fuels, for instance, hydrogen blending in BF-BOF steel plants to produce low-carbon steel, while the medium to long-term looks at complete replacement of coal/gas in H_2-DRI-EAF setups. Countries globally are planning their long-term pathways by adopting newer technologies, fuels and materials in the pathways, although most of them are still at a very nascent stage.

Deploying newer sustainable technologies, cleaner fuels, and materials can be challenging. High upfront costs and green premiums reduce competitiveness compared to conventional counterparts. Simultaneously, a lack of standardisation, fragmented policies, and regulatory uncertainties hinder investment confidence and slow down adoption across industries.

Table 4.4: Challenges and suggestions for deployment of new technologies and fuels

	Key Barriers	Suggestion & Intervention
Technology Maturity & High Costs	**High risks with new technologies/ fuels** Decarbonisation of hard-to-abate sectors relies on technologies like Hydrogen-DRI (Steel), Electric Crackers (Petchem), and Carbon Capture (Cement) that are still in pilot or early commercial stages. Private sector hesitates to invest in "First-of-a-Kind" (FOAK) commercial-scale projects due to technical risks and uncertain returns. Green alternatives have high upfront costs with uncertain returns (e.g., decarbonising steel and cement requires hundreds of billions USD). The "Green Premium" (cost difference between clean and fossil tech) is high, discouraging early adoption. Green and low-carbon suppliers, particularly MSMEs in sectors such as waste processing, recycling, renewable energy, and energy-efficient technologies face high working capital constraints due to delayed payments and limited access to affordable short-term finance. No widely adopted product carbon labels or taxonomy makes it hard to distinguish "low-carbon" products.	**Implement Pilot Projects:** Government along with Multilateral Development Banks (MDBs) to support pilot projects in GH_2-DRI, inert anodes (aluminium), and CCUS-equipped cement plants to demonstrate feasibility and reduce investor risk. **Provide Viability Gap Funding and deploy blended finance for technologies** which have high upfront costs and risks such as GH_2-DRI, CCUS. Introduce **green bill discounting through TReDS** by enabling identification and preferential financing of invoices associated with **verified green and low-carbon goods and services**. This can be supported through lower discount rates, priority bidding windows, or partial risk-sharing mechanisms for eligible invoices. **Ensure assured offtake** through creation of buyer's platform for low-carbon products such as Sustainable Aviation Buyers Alliance, the Zero Emissions Maritime Buyers Alliance and the Sustainable Steel Buyers Platform. These platforms can also leverage Article 6.2/Article 6.4 for enabling trade in low-carbon products. **Strengthen climate taxonomies** to explicitly include all low-carbon process routes/ technologies, with clear benchmarks, and thresholds. Harmonise definitions and reporting boundaries with major international frameworks to reduce transaction costs and uncertainty for investors. **Standardisation initiatives:** Government and industry bodies to roll out Type III eco-labels and rating systems for key materials.

	Key Barriers	Suggestion & Intervention
Domestic Manufacturing and R&D Ecosystem	**Import Dependence:** India currently imports key equipment like high-efficiency electrolysers and advanced membrane technologies. Lack of domestic manufacturing keeps costs high. **R&D Ecosystem:** Many critical industrial technologies for Net Zero (e.g. advanced green hydrogen-based processes, CCUS, Small Modular Reactors (SMRs), inert anodes, novel binders) are still at early development or demonstration stages and require sustained R&D support. Weak industry-academia linkages and limited coordinated research programmes slow progress on addressing key technology bottlenecks.	**Localisation via PLI:** Scale up Production Linked Incentive (PLI) schemes to cover the full value chain of clean technologies. **Dedicated industrial R&D missions and centres of excellence** focused on low-carbon process routes, backed by public grants and matched industry funding. The missions may encourage joint ventures between domestic firms, global technology providers and research institutions so that capital, IP and implementation capabilities are pooled for piloting, scaling and commercialising of low-carbon technologies.
Raw Materials Availability	**Resource Constraints (Cement):** Adoption of LC3 (Limestone Calcined Clay Cement) is slowed by the poor availability and variable quality of kaolinitic clay. **Alternative Fuels:** Industrial players struggle to source consistent quality municipal solid waste and biomass for co-firing, limiting thermal substitution rates. **Critical Mineral Supply:** Domestic manufacturing of electrolysers and advanced batteries depends on imported critical minerals (e.g., Nickel, Lithium, Cobalt, Platinum Group Metals). Global supply concentration and price volatility pose a risk to indigenisation targets.	**Supply Chain Development:** Identify and create calcined clay clusters to secure raw material supply. **Secured Bio-Supply Chains:** Strengthen the supply chain for biomass pellets/briquettes through aggregator incentives and storage infrastructure to ensure year-round availability. **Strategic Sourcing:** Secure long-term international offtake agreements for critical minerals while accelerating domestic exploration and recycling (urban mining) to support local manufacturing of clean-tech components. For further details, Working Group report on Critical Minerals (Vol. 10) can be referred..

4.5 JOBS AND TRADE-ENABLERS OF TRANSITION

For the industrial transition to succeed, technical interventions must be supported by an enabling ecosystem. The scale of investment required is immense, beyond capital; the transition hinges on a skilled workforce capable of operating new green technologies and a trade strategy that protects India's export competitiveness against emerging carbon border taxes. For a detailed assessment of financing needs and social implications of transition, respective Working Group reports (Vol. 9 & Vol. 11) can be referred.

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[18] In cement, ~50% of workers don't feel ready for digital/ low-carbon tech, >50% lack basic digital literacy, while similar gaps exist in aluminium, paper sectors.

Table 4.5: Challenges and suggestions for managing jobs and trade

	Key Barriers	Suggestion & Intervention
Employment Risks and Opportunities	**Workforce skill gap** – Fast adoption of new technologies risks a shortage of 30–32 million skilled workers by 2025, rising to nearly 49 million by 2027 (Bhattacharyya & Philip 2024). There's also a lack of "skills intelligence" systems to anticipate future skill needs from new technologies, leaving training programs reactive and workers underprepared (ILO, 2024). Many current workers, especially in traditional industries, have low digital and technical skills, creating a "transition gap" where new energy-efficient and low- carbon processes can't be adopted readily.[18] Low-carbon transition will phase out certain carbon-intensive jobs, risking unemployment in affected regions if not managed.	**Upskill & reskill at scale:** Sector Skill Councils (SSCs) should institutionalise continuous collaboration with industry partners and ITIs to ensure that training curricula and occupational standards are regularly updated in line with evolving skill requirements. Certification systems must be strengthened through employer-led assessments and periodic third-party audits so that SSC credentials gain stronger labour market credibility and wage signalling value. Greater emphasis must be placed on on-the-job training and practice-oriented courses to upskill the existing workforce, particularly in emerging technologies and new production processes. Sector-specific transition skill roadmaps can identify at-risk occupations and facilitate reskilling into low-carbon roles, enabling firms and workers to adapt smoothly to low-carbon transition pressures. A national skills intelligence system should be developed to generate forward-looking labour market information and forecast future skill demand at sectoral and regional levels. **Develop a national policy** framework for worker retraining, relocation support, and economic diversification in districts affected by industrial decline. Dedicated funding mechanisms, including the District Mineral Foundation for mining regions, can be leveraged alongside coordinated efforts by the Skill India Mission and the SCGJ to transition workers from declining industries into emerging green sectors.
International Competitiveness amid Emerging Trade Barriers	**Carbon border taxes:** Indian steel and aluminium exports face heightened risk due to the EU's CBAM, which comes into effect in 2026, as India ranks among the most exposed countries globally in terms of carbon cost per dollar of EU trade.	**Accelerate low-carbon transition in export-oriented sectors** to upgrade competitiveness. Leverage domestic carbon pricing and Article 6.2/6.4 of Paris Agreement to enable the use of low-carbon technologies/fuels.

	Key Barriers	Suggestion & Intervention
	High import duties on inputs - Protective tariffs on certain inputs make downstream Indian industries less competitive globally than their peers. For example, a 30% antidumping duty on imported bare Printed Circuit Boards (PCBs) raises costs for Indian electronics manufacturers, whereas competitors in countries like Vietnam or Bangladesh import them cheaply. **Lack of green export branding:** Indian products' sustainability advantages are not formally recognised, while global markets increasingly demand certified eco-friendly products. Other markets have initiated programs towards a global edge in exports using such labels (e.g., China's 100 products program).	**Evidence-based tariff policy:** Institutionalise a periodic "tariff stocktake" to assess impact on domestic manufacturing. Recent example: the 2025 Union Budget removed a 2.5% import duty on certain PCB subparts to aid local electronics assembly. Expand such measures by also revisiting high duties like the 30% on bare PCBs. Creating a consultative mechanism with industry stakeholders can guide tariff adjustments to improve export competitiveness while fostering domestic capabilities. **Launch a "Green Stamp" initiative** for exports to certify and showcase the environmental footprint of Indian products. Develop standardised assessment frameworks (analogous to the EU's PEFCR guidelines) for priority export sectors, create credible lifecycle assessment (LCA) data repositories, and implement digital product passports that track product sustainability attributes. With a recognised Green Stamp label, Indian products can stand out in global markets for their low-carbon and sustainable qualities, converting India's sustainability edge into a competitive advantage.

Conclusion

Industrial decarbonisation in India represents both a critical challenge and an immense opportunity. As one of the fastest-growing economies, India's industrial sector is central to its development but also accounts for a significant share of energy use and greenhouse gas emissions. Moving towards low-carbon pathways will require a mix of technology upgrades, electrification, adoption of renewable energy, resource efficiency, and innovative financing mechanisms. At the same time, supportive policies, stronger institutional frameworks, and capacity-building across industries, particularly in energy-intensive and MSME segments will be essential. Achieving this transformation can position India as a global leader in sustainable industrialisation, driving competitiveness, creating green jobs, and ensuring that economic growth aligns with Net Zero commitments.

ANNEXURES

Annexure - I: Macroeconomic Projections

Table I.1: Macroeconomic projections

	2020	2025	2050	2075
Population (millions)	1347	1411	1596	1621

	2025-2050	2050-2070
Real GDP Growth Rate	7% (average)	3.6% (average)

Annexure - II: Emission Factors for Industrial Processes and Product Use

Table II.1: Emission factors for Industrial Processes and Product Use (IPPU)

Industry	Emission Factor
Cement	0.5292 tCO_2/tonne Clinker Produced
Aluminium	Prebaked Technology: 1.6 tCO_2/tonne, 1.45 $kgCF_4$/tonne, 0.44 kgC_2F_6/tonne of aluminium produced
Soda Ash	0.323 tCO_2/tonne Soda Ash
Ethylene	Naphtha Route: 1.73 tCO_2/tonne Ethylene Produced Ethane Route: 0.76 tCO_2/tonne Ethylene Produced

Annexure - III: Grid Emission Factors ($kgCO_2/kWh$)

Table III.1: Grid emission factors ($kgCO_2/kWh$)

2020	2025	2050		2070	
		CPS	NZS	CPS	NZS
0.713	0.710	0.328	0.257	0.067	0.000

Annexure - IV: Cement Composition Table: % Mix of Raw Materials

Table IV.1: Cement composition: % mix of raw materials

	Clinker	Gypsum	Limestone	Fly ash	Slag	Calcined clay
Ordinary Portland Cement (OPC)	90%	5%	5%	0%	0%	0%
Portland Pozzolana Cement (PPC)	60%	5%	0%	35%	0%	0%
Portland Slag Cement (PSC)	25%	5%	0%	0%	70%	0%
Portland Composite Cement (PCC)	25%	5%	0%	35%	30%	0%
Limestone Calcined Clay Cement (LC3)	50%	5%	15%	0%	0%	30%

Annexure - V: Fertiliser Production Projection Methodology

Fertiliser use is derived from food grains requirement, which are estimated based on population growth projections. Then, fertiliser nutrients demand for estimated food grains production is calculated.

Demand for fertiliser nutrients has been estimated based on the following approach:

f. Estimation of requirement of food grains for the projected population

g. Applying response ratio of fertiliser to food grains to arrive at fertiliser demand for food grains. This ratio is assumed to improve from 1:5.4 in 2023-24 to 1:10 by 2070, reflecting more efficient fertiliser use through balanced application and integrated nutrient management practices.

h. Estimation of total demand of fertiliser nutrients by taking into account the share of other crops in total fertiliser use.

i. Estimates of demand for individual fertiliser nutrients by taking nutrient use ratio in to account. Fertiliser nutrient use ratio is assumed to improve gradually from 10.9:4.4:1 in 2023-24 to 4:2:1 by 2047 and remain constant through 2070.

The resulting projections of demand for fertiliser nutrients from 2024-25 to 2069-70 are listed in the table below:

Table V.1: Projected demand for fertiliser nutrients from all sources (million tonnes)

Year	N	P_2O_5	K_2O	Total
2023-24 (Actual)	20.5	8.3	1.9	30.6
2049-50	28.5	14.2	7.1	49.8
2069-70	34.3	17.2	8.6	60.1

From these quantities, gross nutrient requirement from all sources is estimated. The actual nutrient requirement from chemical fertilisers is projected by subtracting nutrients available from organic sources from the total nutrient requirement.

Nutrient Realisable from Organic Sources

In recent years, the Government of India has been taking various measures to encourage use of other sources also along with balanced fertilisation for higher agricultural productivity. Some of these measures include 100% coating of urea with neem oil, resizing of urea bag to 45 kg from 50 kg, encouragement of the use of nano fertilisers, organic fertilisers, bio-fertilisers, potash derived from molasses, coverage of higher area under micro irrigation for use of 100% water soluble fertilisers, promotion of city compost, etc. According to the Annual Report 2022-23 of National Centre for Organic and Natural Farming, total production of organic fertilisers was 76.4 million tonne in 2022-23. Production of bio fertilisers in carrier form was 325.6 thousand tonne and liquid based 557 million liters during 2022-23. In addition, during 2023-24, about 204.14 lakh bottles each of 500 mL nano urea and 44.58 lakh bottles each of 500 mL nano DAP were sold. Further, there was sale/consumption of water-soluble fertilisers of about 220 thousand tonne in 2022-23. Gradual increase in the use of these fertilisers will supplement the use of conventional fertilisers in the coming years, thereby improving nutrient use efficiency for higher agricultural productivity. Based on this, gross nutrient requirement from all sources, nutrient realisable from organic sources, if tapped fully, and actual nutrient requirement from chemical fertilisers are projected, shown in Figure below:

Table V.2: Demand projection of fertiliser nutrients (million tonnes)

Year	Gross nutrient requirement	Nutrient realisable from organic sources and other products	Actual nutrient requirement from fertilisers
2024-25	31.4	3.5	27.9
2049-50	49.8	9.4	40.4
2069-70	60.1	20.9	39.2

Demand Projection of Major Fertiliser Products

Based on the actual fertiliser nutrient requirement, demand for major fertiliser products viz. Urea, DAP, NP/NPKs, SSP and MOP has been worked out for the projected years. During 2023-24, share of nitrogen through Urea to total nitrogen consumption was about 80.5%. To move towards balance fertilisation, use of Urea would go down gradually to 75% by the end of 2036 and will continue till 2070. In case of phosphate, share of P through DAP to total P consumption was 60% in 2023-24. It is estimated that its share will come down gradually to 55% by the end of 2070. However, share of P through NP/NPK and SSP to total P consumption was 31% and 8.8% in 2023-24, respectively. It is estimated that its share will move up gradually to 33% and 12%, respectively, by the end of 2070. Similarly, in case of potash, share of K through MOP was 52.5% in 2023-24 which would improve gradually to 55% by the end of 2070. These assumptions have been applied to work out the product-wise demand for the projected period. Table below shows the net demand projection of major fertiliser products such as, Urea, DAP, NP/NPKs, SSP and MOP from 2024-25 to 2069-70.

Table V.3: Demand projection for major fertiliser products (million tonnes)

Year	Urea	DAP	Complex Fertiliser
2024-25	36	11	11
2049-50	44	15	14
2069-70	51	15	17

Indigenous Supply Projection of Major Fertiliser Products

Production of urea, DAP and complex fertilisers during 2023-24 was at 31.41, 4.29, and 9.54 million tonnes, respectively. Consumption of urea, DAP and complex fertilisers was at 37.78, 10.81 and 11.07, respectively during 2023-24. Therefore, the level of self-sufficiency during 2023-24 on urea, DAP and Complex fertilisers was at 83%, 40% and 86%, respectively. For DAP and NP/NPK complex fertilisers the self-sufficiency is assumed to increase marginal, due to high dependency on imported raw materials & intermediates. In the case of urea, it has been assumed that at least one new urea plant of 1.27 million tonne would be commissioned in every five-year period. Accordingly, the indigenous supply projection of major fertiliser products has been projected.

Annexure - VI: Equivalency Factors for the Conversion of Crude Oil to Oil Products

Table VI.1: Equivalency factors for the conversion of crude oil to oil products

Product	Typical Yield (% of Crude Oil)
Petrol	20-25
Diesel	38-45
ATF/SKO	8-10
Naphtha	2-2.5
LPG	4-5
Fuel Oil	10-12
Bitumen/Pet Coke	9-10
Sulphur	0.5-1
Fuel & Loss	8-10

Annexure - VII: Sector Specific Circularity Challenges & Suggestions

Table VII.1: Sector specific circularity challenges & suggestions

	Challenge	Suggestions
Steel	⏩ Quality of scrap is low ⏩ There is limited deployment of advanced sorting and processing technologies like shredders, magnetic separators, and optical sorters. ⏩ Contaminated scrap results in less yield and more energy consumption. ⏩ Dependence on imports raises risks of export restrictions, taxes, and conservation measures. ⏩ Disruptions to the supply chain (for example, conflicts and a sudden increase in shipping costs) increase price volatility	⏩ Better pre-treatment methods for scrap, for instance, shredding ELVs and removing contaminants, must be developed. ⏩ Scrap quality standards as well as inspections should be introduced. ⏩ Scrap sourcing must be diversified and supply chains made resilient.
Cement	⏩ Construction and demolition (C&D) waste is often contaminated and inconsistent, making processing difficult. India generates an estimated 150–500 million tonnes of C&D waste annually, but only a tiny fraction is recycled. ⏩ Limited logistical capability to collect and transport waste from demolition sites to recycling plants. ⏩ Limited urban space for establishing recycling facilities. ⏩ Limited technical capacity to produce uniform, high-quality recycled aggregates or fuel (RDF) from municipal waste. Heterogeneous waste fuels (RDF from municipal solid waste) often have inconsistent calorific value and high moisture or chlorine content, which can affect kiln operations. ⏩ Cement kilns need reasonably uniform, high-energy-value fuel feed. Indian municipal waste, in contrast, is often wet and mixed with inert material. ⏩ Cheap virgin materials, lack of tipping fees or financial incentives for using scrap make recycled alternatives less competitive.	⏩ Invest in advanced processing technologies (such as smart crushers, heat/mechanical treatment) to separate cement paste from aggregates. ⏩ Pre-processing like drying and shredding is required to make RDF, and removing problem elements (chlorides, heavy metals) is necessary to avoid kiln corrosion or air emissions issues. ⏩ Collection and transport of C&D waste should be organised. ⏩ Financial incentives such as tipping fees for waste usage should be introduced.

	Challenge	Suggestions
Aluminium	⏩ Scrap quality issues (similar to steel), costly segregation, and dominance of informal recycling. ⏩ Exposure to global supply shocks due to import dependence. ⏩ Scrap imports are taxed at higher rates than finished aluminium, thereby discouraging recycling. ⏩ Contradictory positions taken by primary producers and recyclers adds to the problem. For example- Aluminium Association of India (AAI) and FIMI (Federation of Mineral Industries) support 10% duty whereas MRAI (Metal Recycling Association of India) wants zero duty.	⏩ Apply zero or minimal import tariffs on metal scraps (e.g. 2.5%). ⏩ Prioritizing the setting up of Zorba sorting technology, with a focus on promoting domestic manufacturing of advanced sorting equipment ⏩ Provide subsidies for setting up advanced sorting and smelting facilities. ⏩ Encouraging joint ventures or strategic partnerships between automobile manufacturers and secondary aluminium smelters ⏩ Actively attracting foreign direct investment from global auto parts manufacturers into India.

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सत्यमेव जयते

NITI Aayog