



IIM

Metallurgy
Materials Engineering
The Indian Institute of Metals-Delhi Chapter

MET INFO

AUGUST 2026

The Indian Institute of Metals Delhi Chapter

39, Tughlakabad Institutional Area
M B Road, Near Batra Hospital, New Delhi-110 062

Tele: 011-20880099

@ iim.delhi@gmail.com



www.iim-delhi.com

An Inhouse Publication

For internal Circulation Only

Contents

	Description	Page
1	IIM Delhi Chapter Executive Committee: 2026-27	3
2	IIM Delhi Chapter Executive Committee Members: Contact Details	4
3	Global Steel Industry in 2025	5
4	Approach to Shaping Transformation of the Steel Industry	9
5	Steel Production in India in FY2026-27: Forecast	13
6	SAIL Receives EC for Bhilai Steel Plant Expansion	14
7	Water may become a Bigger Constraint than Iron Ore	14
8	How AI is Re-forging India's Steel Industry	15
9	China's AI Steel Hub	18
10	India's Sector - wise Steel Demand	19
11	India's Stainless Steel Production	22
12	Red Mud to be Aluminium Industry's Next Resource Frontier	23
13	Aluminium Dross Processing: Generation, Recovery and Strategic Roadmap	25
14	Aluminum-Lithium Alloys	28
15	Commitments for Recycling Critical Minerals Scheme Treble	29
16	Global Energy Consumption Continued to Rise in 2025	30
17	India is Likely to Witness a 4–6x Increase in Critical Mineral Consumption by 2040	32

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Special Invitee



Prof S Basu

Executive Committee Members: Contact Details

Name / Designation	Affiliation	Contact No / E-Mail
Shri Manoranjan Ram <i>Chairman</i>	Vice President – Sales & marketing Danieli Group	9910014989 manoranjanram@yahoo.com m.ram@danieli.com
Shri Deepak Jain <i>Vice Chairman</i>	Former Dy. Director General (W) BIS	9868640986, 8368622619 deepakjain7177@gmail.com
Shri N K Kakkar <i>Vice Chairman</i>	Former Vice President Somani Kuttner India Pvt. Ltd.	9871008505 nirmalkakkar@gmail.com
Shri K R Krishnakumar <i>Hon. Secretary</i>	Ex CGM SAIL & Former Consultant, Ministry of Mines	9818277840; 01202773861 kuduvak059@gmail.com kuduvakrishna@yahoo.co.in
Shri Ramesh Kumar Narang <i>Hon. Treasurer</i>	Former Head (Corporate Affairs) BALCO New Delhi	9899298857 rknarang62@gmail.com
Ms Chandana Arjun <i>Hon. Jt. Secretary</i>	Manager - Design Technotherma India Pvt. Ltd	8547621796 chandanaacalicut@gmail.com
Shri Ashok Kumar <i>Hon. Jt. Secretary</i>	Ex General Manager SAIL, New Delhi	8076904331 akdel12@gmail.com
Shri K K Mehrotra <i>Member</i>	Ex CMD MECON Limited	9868112514; 01203645267 kishorekmehrotra@gmail.com
Shri R K Vijayavergia <i>Member</i>	Ex Executive Director (Operations), SAIL & Former Consultant, SRTMI	9650155544 rkv.sail@gmail.com
Dr. Ramen Datta <i>Member</i>	Ex General Manager, RDCIS, SAIL & Former Consultant, SRTMI	9958084110 dattaramen@gmail.com
Shri N Vijayan <i>Member</i>	Director Technotherma India Pvt. Ltd.	9818695690 technothermaindia@gmail.com
Shri G I S Chauhan <i>Member</i>	Ex Executive Director I/c, RDCIS, SAIL	9717302437; 7048993116 gisc.delhi@gmail.com
Shri Ram Gopal <i>Member</i>	Ex Executive Director SAIL	9968605059 ramgopal.sail@gmail.com
Shri B R Jain <i>Member</i>	Sr. Adviser Engineering Council of India	9313190011 jainbinay@gmail.com brjeci@gmail.com
Shri R K Singhal <i>Member</i>	Consultant - Communications Professional Golf Tour of India & Ex Consultant, SRTMI & Ex Executive Director (Corporate Affairs), SAIL	9910055630 rksh.singhal@gmail.com
Shri R K Sinha <i>Member</i>	Ex Director (Operations) Modern Steels Ltd	8968684955 rksinha555@gmail.com
Shri Neeraj Nautiyal <i>Member</i>	Senior Vice President Yogiji Digi Pvt Ltd	9811956565 nautiyal_n@yahoo.co.in
Shri Rajesh Singh <i>Member</i>	Director MAS Group	9711200181 r.singh@masgroup.in
Prof. Suddhasatwa Basu <i>Special Invitee</i>	FIPI Chair Prof. (HAG) IIT Delhi	7838134181 drsbasu@gmail.com

Global Steel Industry in 2050

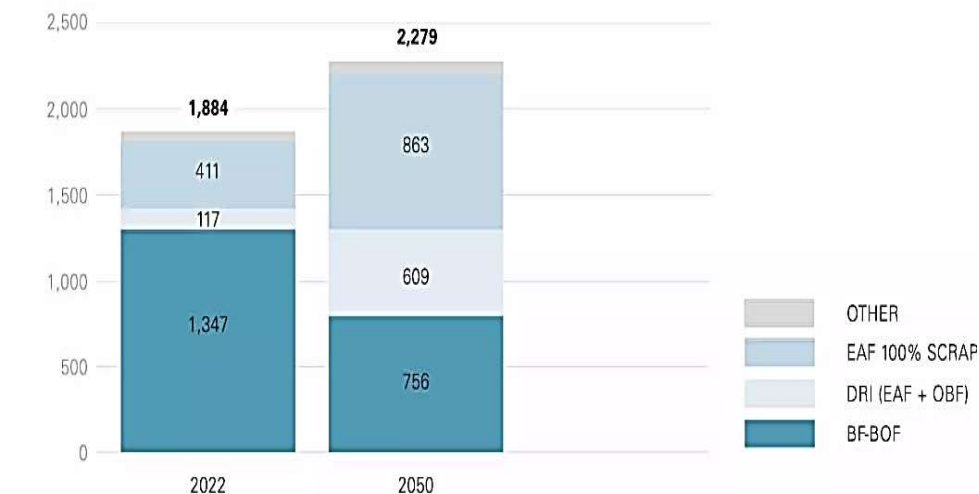
The challenge is clear: To combat climate change, steel must become “green”. However, the pathway towards green steel depends on many variables from steel demand to energy supply and raw material availability.

Today, 8 billion people on Earth “consume” around 1.8 billion tons of steel annually. This translates into roughly 222 kg of steel per person each year. However, there are huge differences. The apparent steel use per capita ranges from 310 kg in Europe to around 30 kg in Africa.

The United Nations forecasts a global population of almost 10 billion in 2050. At today’s apparent steel use per capita, that will require an annual steel production of around 2.2 billion tons. However, many forecasts also anticipate a surge in steel demand per capita in populous regions such as India or Africa. This could drive steel production up to around 2.75 billion tons per year.

At the same time, the transformation of the energy grids to renewable energies will change the demand for steel. Presently, a mere 1% to 3% of steel is used for energy infrastructure. However, this figure is expected to rise significantly, exceeding 10%, especially for the construction of wind turbines or photovoltaic systems. The burgeoning electrification trend will also increase the demand for silicon steels.

So, how can we produce more steel and yet reduce CO₂ emissions? One part of the equation is the existing plant infrastructure. Given their long investment cycles, plants and equipment will only be renewed step by step.



Steel production in 2050 (in million t/year at constant a steel consumption per capita)

Steel production in 2050 (in million t/year at constant a steel consumption per capita)

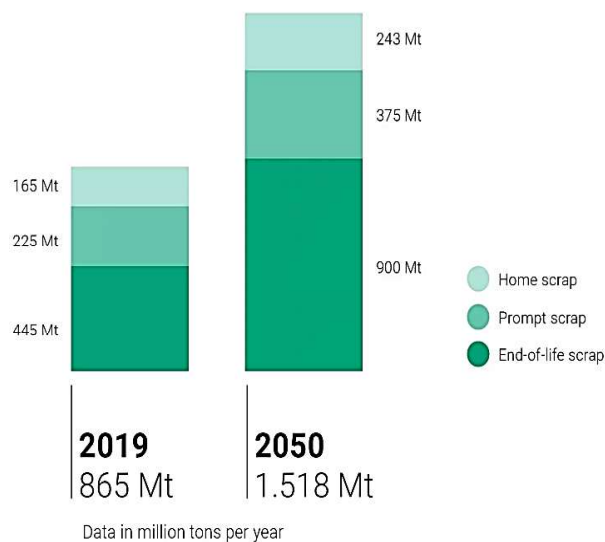
In 2025, 69.4% (~ 1,285 million tons) of steel was produced using the traditional BF - BOF (Blast Furnace-Basic Oxygen Furnace) route. This method produces an average of 2.34 tons direct CO₂ emissions per ton of steel. Another 30.3% of the total volume was produced via the scrap/DRI route with electric furnaces (CO₂ intensity of 1.47 and 0.69 tons per ton of steel on average respectively for DRI-EAF and Scrap-EAF).
{Data updated as per 2026 World Steel in Figures published by WSA}

Scrap-based steelmaking: poised for significant growth

The electric steel route is the fastest way to produce near-zero emissions steel, as long as green electricity is used. But how much scrap will be available in the future? The World Steel Association expects end-of-life scrap to more than double from today's 445 to around 900 million tons in 2050. Adding scrap from steel processing (prompt scrap) and internal scrap from steelmaking (home scrap), we can expect a total of up to 1.4 billion tons of scrap to be available each year.

However, not all of this will be available for the electric steel route. Much like today, a good third of this scrap will be used in primary steelmaking, i.e., the DRI-EAF route, and as cooling scrap in remaining BOF converters. Taking into account the typical yield losses of the EAF, we can project steel production quantities of between 850 and 900 million tons via direct scrap recycling. That would represent an increase from today's 23% to more than 35% of total steel production. The rising concentration of tramp elements like copper, lead, and tin necessitates scrap processing of further dilution.

„HOW MUCH SCRAP WILL BE AVAILABLE IN THE FUTURE?“
 EXPECTATION OF THE WORLD STEEL ASSOCIATION



In 2050, scrap availability will rise to more than 1.5 million t/year.

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The availability of high-quality iron ore will be a limiting factor

While the EAF route may account for a third of the steel output by 2050, the remaining two-thirds will be based on virgin material. Even if scrap was abundantly available, for certain high-quality grades, there is no alternative to virgin material. That's because the accumulation of tramp elements in scrap makes it impossible to produce all grades on the secondary route.

Most green steel projects today rely on direct reduction plants. H2 Green Steel is a pioneering example for many greenfield projects, relying entirely on green hydrogen and green electricity generated from hydropower and other renewable energies.

In a two-step process, direct reduction can also replace the traditional blast furnace in existing steelworks. Here, natural gas will be gradually replaced by hydrogen for reduction. The electric smelter (OBF, Open Bath Furnace) can enable the production of hot metal, seamlessly integrating into the existing works infrastructure.

Several critical hurdles impede the exclusive adoption of direct reduction as the ultimate solution. The most important factor is that shaft-based direct reduction requires the use of high-quality (>67% Fe and <2% acidic gangue) iron ore pellets.

To bolster the supply of these high-grade pellets, large sums have to be invested in the development of new, high-quality iron ore deposits, for example, in West or Central Africa. The beneficiation and enrichment of low-grade ores will also be increased despite the high cost and the resulting high quantities of tailings. In the upcoming decades, technologies may be developed, tailored for the direct reduction of these lesser-grade ores. Yet, despite these developments, the availability of high-quality iron will remain a critical factor.

The battle for green hydrogen

The growth trajectory of the direct reduction route is not without its challenges. All scenarios anticipate that natural gas will be replaced by green hydrogen as a reducing agent for direct reduction, at least in the medium term. Steelmaking is the field in which the use of hydrogen is the most efficient because every ton of hydrogen saves around 28 tons of CO₂. Nevertheless, the steel industry will face intense competition for the scarce resource hydrogen. Other sectors, including the chemical industry, also have their eyes set on hydrogen for decarbonization. Plus, its potential applications in transportation and heat generation may add to the demand.

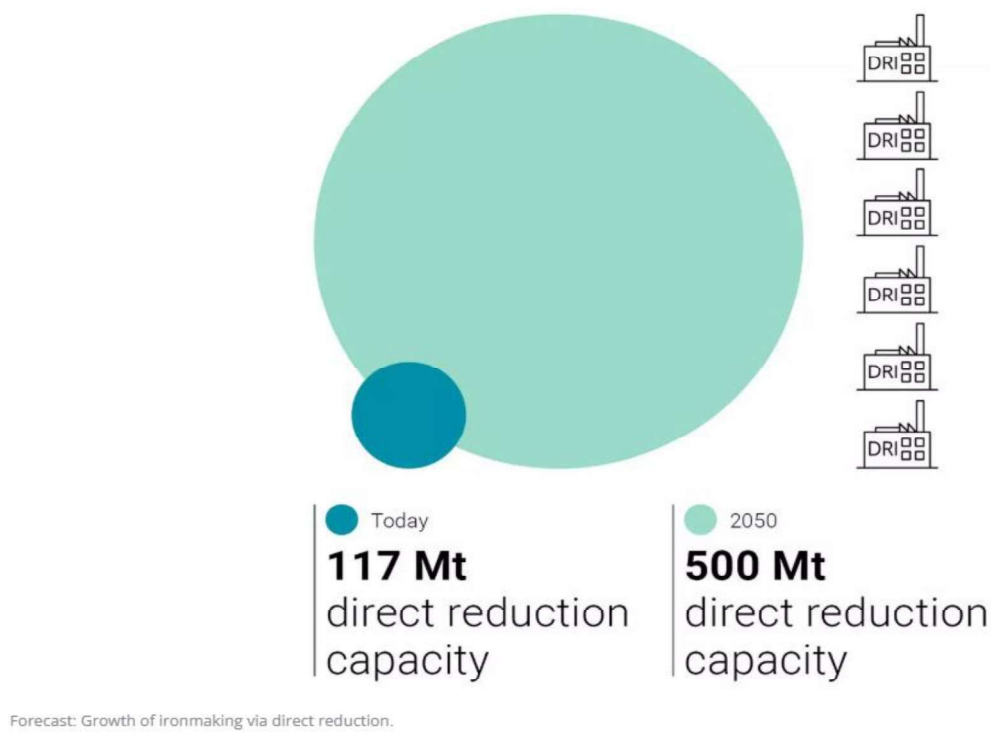
Industrial-scale green hydrogen production through electrolysis calls for a significant ramp-up of wind and solar energy infrastructure. A complete conversion of the blast furnace capacity to green hydrogen-based direct reduction would require the additional production of around 4,600 terawatt hours of electrical energy – about

20% of today's global electricity consumption. This figure alone illustrates the extent of the challenge ahead.

Given these complexities, forecasts expect direct reduction production to grow from today's 153 million tons to almost 500 million tons by 2050. For that to happen, another bottleneck must be resolved: plant engineering. In recent years, an average of two new full-scale direct reduction plants has been built globally each year. To achieve an annual capacity boost of approximately 15 million tons, the construction of six to eight DRI plants per year would be required, needing engineering and order execution capabilities. *{Data updated as per 2026 World Steel in Figures published by WSA}.*

A plea for openness Summing up Outlook

Depending on the development of per capita steel use, experts assume a global annual crude steel production of between 2.32 and 2.75 billion tons. Under the lower scenario, around 20% (approx. 500 million tons) will come from direct reduction, while the electric steelmaking route will account for 35% to 40% (approx. 900 million tons). In addition, we'll see the emergence of new processes, such as iron ore electrolysis, which are currently under development. Even under optimistic assumptions, no capacity of more than 50 to 100 million tons can be expected over these new routes by 2050.



Forecast: Growth of ironmaking via direct reduction

Different regions and nations will pursue different paths towards decarbonization. Direct reduction technology will see the most significant growth in countries with access to high-quality iron ores and low-cost energy sources such as solar and hydroelectric power. The electric arc furnace route, on the other hand, is poised for substantial expansion in countries with rising scrap availability.

In China, an influx of scrap resources is anticipated by the 2040s, as infrastructure established in the late 20th and early 21st century gets renewed.

However, all forecasts also show that the blast furnace route will continue to play a major role for the next three decades. Come 2050, almost 40% (approx. 850 million tons) of world crude steel will be produced using the conventional route. That is why the conversion of blast furnaces into low CO₂ emission operation is the key challenge to decarbonize the steel industry.

Source: thyssenkrupp Steel Europe (data updated)

Approach to Shaping Transformation of the Steel Industry

Creating a sustainable global steel industry brings with it major challenges for both plant owners and plant builders. As the transformation progresses, this calls for a long-term plan and the right technologies to respond to local market conditions, while at the same time ensuring the lasting economic success of companies operating in the steel industry.

Current requirements in the steel industry in terms of decarbonization and sustainability

The steel industry is about to undergo a fundamental transformation that is characterized by global factors and regional conditions, including, for example, the availability of resources and the energy costs involved. State regulations also play a crucial role, as these have a significant influence on both the pace and the direction of decarbonization efforts.

Electric steelmaking is predominant in the United States, accounting for around 70% of total steel production. The key to decarbonization lies more in the way the electricity itself is generated. What's more, North America is seeing growing demand for direct reduced iron (DRI) facilities, as these provide the high-purity starting material, which is indispensable for producing quality steels and can also be further processed in the electric arc furnace (EAF).

In Europe, the focus is on replacing blast furnaces with DRI equipment. This is due to ambitious decarbonization targets and specific state funding programs. However,

challenges such as the availability of raw materials and high energy costs are currently dampening interest in new investments. A further expansion of EAF capacities is also in sight.

India's strategy is shaped by existing resources. Integrated steel production based on conventional blast furnaces continues to dominate, as local coal and iron ore deposits are widely available.

China is guided by targets, such as the expansion of renewable energy, to move forward with its decarbonization goals. Industry overcapacity could act as a catalyst for decarbonization, as outdated facilities are increasingly being taken out of service.

At the same time, China is investing in direct reduction plants and conducting research into solutions for the gradual decarbonization of conventional blast furnaces.

Japan, South Korea, and other Asian countries are also pursuing long-term decarbonization strategies. These countries are banking heavily on hydrogen as their main energy source in the future, in order to reduce dependence on imported coal. They are investing in innovative technologies and developing strategic partnerships to achieve their ambitious objectives.

Latin America is uniquely positioned to lead the global decarbonization of the metals industry.

Changes needed in existing plant and equipment

The global steel production landscape is facing radical change. It is expected that worldwide steel production will increase to around 2.3 billion tons per year by 2050.

As a result, there is a growing need to expand sustainable production capacities. Right now, around 70% of steel is produced using blast furnaces. By 2050, we expect this figure to fall to around 30%.

This means that around half of today's 1.35 billion tons per year made by the conventional blast furnace route needs to be decarbonized.

At the same time, the share of direct reduction processes is set to increase considerably. At present, the DRI process accounts for only six percent of annual steel production. By 2050, we expect this to grow to around 25%, corresponding to around 500 million tons.

The proportion of scrap-based steel production will also rise substantially. Today, scrap makes up approximately 20% of global steel production, but by 2050 this is set to rise to almost 40%.

Factors which will determine the worldwide introduction of different steel production routes

The introduction of sustainable steel production processes is influenced, to a decisive degree, by the availability of raw materials and energy sources as well as by national politics. The conventional blast furnace process is based on iron ore and coal, which are available in large quantities around the world. This secures the dominance of this process, especially in countries such as India and China, which have considerable domestic resources and an established infrastructure.

The transition in Europe to sustainable scrap-based steel production using electric steelmaking requires sufficient quantities of high-grade steel scrap and green electricity. Alternatives such as hot briquetted iron (HBI) could supplement scrap, but their production would also have to be sustainable, which in turn requires scarce resources such as green hydrogen and green electricity.

Up to now, direct reduction processes have mainly used natural gas, which has limited their application to regions that are rich in natural gas, including the Middle East, North Africa, and Central America. In Europe, high natural gas prices are hampering the expansion of DRI plants and, in the past, have resulted in the ongoing use of integrated steel production routes. In particular, green hydrogen and green electricity are essential if the direct reduction process is to be introduced successfully in Europe. This will apply especially to countries with favorable conditions for renewable energies, such as Scandinavia, Spain, and Portugal. The European Union stipulates that 90% of the energy used for green hydrogen production comes from renewable sources, which poses significant challenges in countries like Germany and other Central European nations.

Another key factor is the availability of high-grade iron ore. The global trade in iron ore pellets suitable for DRI currently stands at only around 10 million tons per year, which is by no means sufficient to replace blast furnaces on a large scale. Raw materials account for around 60% of the costs of producing every ton of steel using the DRI process, which underlines the importance of a sustainable supply of raw materials and energy-efficient solutions.

Current projects for sustainable steel production in Europe vis a vis availability of raw materials and green energy

The initial wave of investment in DRI facilities was often guided by the classical minimill model, with the integration of direct reduction and electric steelmaking plants to replace blast furnaces. These projects had significant backing in the form of substantial state support, particularly in Germany. Nevertheless, important questions regarding the availability of raw materials and energy costs still need to be

answered. In addition, DRI plants have so far not been operated entirely with hydrogen. The first projects in Sweden and Germany are pursuing this goal, but they must also meet the challenge of scarce resources, including high-quality iron ore and green electricity. One of the consequences of this is a noticeable slowdown in European investment in DRI plants. Steel producers are closely following the results of ongoing projects, in particular the transition to hydrogen-based processes. The financial market is also hesitant, as investors evaluate the performance and outcomes of current projects. Open bath furnaces (OBF) and submerged arc furnaces can help provide a solution here, as these, unlike EAFs, can process larger slag volumes. This allows the use of conventional blast furnace ores, thus reducing operating costs and enabling downstream facilities, such as the converter shop, to be retained.

Midrex® direct reduction process is the industry's most productive technology for making high-quality direct reduced iron (DRI) products.

Fully decarbonizing the metals industry

Decarbonizing the metals industry is a decades-long project that will require considerable investment. The installed base is too large to transform it in one go, and global demand cannot be met solely by scrap and hydrogen-based production routes.

Decarbonizing downstream processes of iron and steel production

Decarbonizing downstream process stages is based on four pillars: energy recovery, electrification, fuel switch, and digitalization. The integrated casting and rolling process does away with energy-intensive slab reheating. Furthermore, the process-related disconnection of the roughing stand and the finishing mill means that the various process stages can be optimized without having to consider the process as a whole. By using induction furnaces, natural-gas operated systems, such as the tunnel furnace, can be replaced with electrical technologies.

Generally, automation and digitalization have a major influence on the efficiency and sustainability of downstream process stages. Autonomous operation of plants and equipment through self-optimizing processes keeps human interventions to a minimum. By integrating data from all automation and digital systems, comprehensive insights are gained into the condition of the plants, quality management, production planning, and energy consumption. Predictive solutions enable contradictory KPIs to be harmonized and the value chain as a whole to be optimized.

Source: SMS Group magazine

Steel Production in India in FY2026-27: Forecast

In the 2026-27 financial year (FY), steel production in India is set to rise by 8% year-on-year — to 183 million tonnes, up from 169 million tonnes in the 2026 FY.

The rate of production growth will slow slightly compared to 11% y-o-y in FY2026. This is due to a more restrained expansion of capacity (forecast: +6% to 248 million tonnes in FY2027), reflecting producers' cautious approach amid sustained pressure on margins and geopolitical risks (notably the conflict in the Middle East).

Thanks to the recent recovery in finished steel prices and improved profitability, capacity utilisation in FY2027 will rise to 75%.

Domestic steel consumption in FY2027 will accelerate to 9% y-o-y (175 million tonnes) compared to 6% y-o-y in FY2026.

The main driver of the market is government funding:

1. Government capital expenditure. The allocation of 12.2 trillion Indian rupees from the budget for capital expenditure will help offset weak investment activity in the private sector.
2. Construction and infrastructure. These sectors will account for an 8 million tonne increase in steel demand. This positive trend is confirmed by cement producers (growth forecast: 7–8% y-o-y) and the expansion of the PM Awas Yojana housing programme, whose targets for FY2027 are three times higher than last year's.

Steel consumption in engineering and industrial manufacturing will slow growth to 5 million tonnes (compared to 7 million tonnes in FY2026). This segment is being held back by high energy prices, inflation and disruptions to supply chains. However, the sector will be supported by government incentive schemes (PLI) and stable demand in the automotive sector.

Steel consumption in the country has doubled over the last decade — from 77 million tonnes in 2014–2015 to 152 million tonnes in 2024–2025. India's steel production capacity is set to reach 300 million tonnes by the 2030/2031 financial year and 400 million tonnes by the 2035/2036 financial year.

India will increase iron ore production by almost 8% year-on-year in the 2026-27 financial year, to 340–345 million tonnes. In the 2025-26 financial year, the country increased its ore production by 7% year-on-year to 310 million tonnes.

Source: BigMint

SAIL Receives EC for Bhilai Steel Plant Expansion

SAIL has received environmental clearance for the expansion of its Bhilai Steel Plant, increasing hot metal capacity from 7.5 mnt/year to 8.8 mnt/year and crude steel capacity from 7.0 mnt/year to 8.3 mnt/year. The project includes a new blast furnace No. 9 with an estimated volume of 4,500 cubic meter, a 0.8 mnt/year coke oven battery, and sinter plant upgrades. After commissioning BF No. 9 and phasing out BF 1-3, total active blast furnace volume will rise modestly to around 16,080 cubic meter from 14,679 cubic meter.

Water may become a Bigger Constraint than Iron Ore

India plans to increase steel production from ~170 Million Tonnes today to 500 Million Tonnes by 2047. The industry is discussing Green Hydrogen, Decarbonisation, CBAM, Renewable Energy and Carbon Capture, but not WATER, at least not as much as it deserves.

Steel production depends on water—from raw material handling, coke ovens, blast furnaces and steel melting shops to casting, rolling and finishing operations.

The next generation steel plant cannot operate on *Water Intake → Process → Discharge*. It must operate on *Water Intake → Process → Recycle → Reuse → ZLD*. Effluent Treatment Plant (ETP) and Zero-Liquid-Discharge system (ZLD) are no longer environmental compliance tools. They are strategic business assets. They create value by recovering 90–99% of water, securing future capacity expansion, reducing dependence on freshwater sources, improving ESG and sustainability ratings, supporting green steel positioning, enhancing community acceptance, reducing regulatory and operational risks, strengthening CBAM and export readiness.

Tomorrow's steel plant performance will not be defined only by EBITDA per tonne, CO₂ intensity or energy consumption. It will also be measured by: Water Productivity (m³ of water per tonne of steel).

The companies that master ETP, Water Recycling and ZLD today will secure their license to grow tomorrow.

As steel capacities continue to grow, advanced water recycling, ETP, and ZLD systems will become strategic enablers rather than just compliance requirements. Water efficiency is clearly emerging as a key competitive advantage for the industry.

While the industry is hyper-focused on carbon footprints, green hydrogen, and CBAM readiness, water security remains the silent constraint that could stall India's

ambition of increasing production of steel in coming decades. Next-generation steel production isn't just about reducing emissions; it's about decoupling growth from freshwater dependence. Implementing Zero Liquid Discharge (ZLD) and advanced recycling isn't just a regulatory checkbox anymore, it is a core strategy for business resilience and risk mitigation. Water productivity (m³/per ton of steel) will soon become as critical a metric as cost per ton.

Steel Plant	Company	Capacity	River / Source	Govt. Allocation	Water Requirement	Recycling	Risk	Key Water Efficiency Management
AMNS Hazira	AMNS India	*9-10 MTPA	Arabian Sea	*150-250 MLD	*250-400 MLD	*96-98%	Medium	Desalination and seawater cooling
AMNS Rajayyapeta	AMNS India	Planned *17.8 MTPA	East Coast Andhra coastal	Under phased allocation	*500-900 MLD	Target >95%	Very High	Expected desalination and digital water twin systems
Bhilai Steel Plant	SAIL	*7-7.5 MTPA	Mahanadi Basin	*350-500 MLD	*450-650 MLD	*85-92%	Medium-High	BF cooling recycle, RM recycle systems
Bokaro Steel Plant	SAIL	*5.8 MTPA	Damodar Basin	*270-410 MLD	*350-500 MLD	*90-95%	Medium-High	Clarifiers, sewage reuse, BF
Burnpur / IISCO Steel Plant	SAIL	*2.5 MTPA	Damodar / Barakar	*150-250 MLD	*220-320 MLD	*85-92%	Medium-High	Modern BF cooling, recycle clarifiers,
Durgapur Steel Plant	SAIL	*2-2.5 MTPA	Damodar Basin	*120-180 MLD	*180-250 MLD	*80-90%	Medium-High	Legacy recycle systems under
Jindal Stainless Kalinganagar	Jindal Stainless	*2.2 MTPA	Brahmani Basin	*33 MLD	*22-35 MLD	*90-95%	Medium	Cooling tower recycle, ETP reuse
Jindal Steel Angul	JSPL	*6 MTPA; target 12-25	Brahmani Basin	*122 MLD current allocation	*329-535 MLD	*92-97%	Very High	CDQ, condensate recovery, gasification recycle
JSW JFE Jharsuguda	JSW Steel & JFE	*0.5-1 MTPA downstream	Mahanadi Basin / Ib River	*15-30 MLD	*20-40 MLD	*90-95%	Medium	Downstream coated steel recycle systems and utility optimization
JSW Salem	JSW Steel	*1 MTPA	Cauvery	*20-40 MLD	*25-50	*90-95%	Medium	Utility recycle systems
JSW Steel Dolvi	JSW Steel	*10 MTPA	Amba River / Coastal	*120-180 MLD	*180-330 MLD	*95-98%	Medium	Seawater integration, coastal recycle
JSW Steel Vijayanagar	JSW Steel	*13-15 MTPA	Tungabhadra Basin	*200-350 MLD	*350-550 MLD	*95-97%	High	ZLD and AI-based monitoring
Lloyds Metals & Energy	Lloyds Metals	*1.2-1.5 MTPA expanding	Wainganga / Godavari linked	*40-80 MLD	*60-120 MLD	*85-92%	Medium-High	Mining-water integration and beneficiation recycle
Rourkela Steel Plant	SAIL	*4.5-5 MTPA	Brahmani Basin	*320-450 MLD	*400-550 MLD	*88-94%	High	Closed-loop cooling modernization
Tata Steel Jamshedpur	Tata Steel	*11 MTPA	Subarnarekha Basin	*250-400 MLD	*350-550 MLD	*96-98%	Medium-High	4R strategy, sewage reuse, rainwater harvesting, digital monitoring
Tata Steel Kalinganagar	Tata Steel	8-13 MTPA	Brahmani Basin	*60-90 cusecs	*150-250 MLD	*95-97%	Medium-High	STP reuse, advanced recycling
Tata Steel Meramandali	Tata Steel	*5.6 MTPA	Brahmani Basin	*120-180 MLD	*180-300 MLD	*92-96%	High	DRI-EAF recycle systems, wastewater
Vizag Steel Plant	RINL	*7.3 MTPA	Yeleru Canal +	*250-400 MLD	*350-500 MLD	*88-94%	High	Large recirculation systems
Water Management estimated Status across Indian steel Industry								

Source: LinkedIn post

How AI Is Re-forging India's Steel Industry

India's steel industry has long been associated with scale, heat, and heavy engineering. But today, a quieter transformation is underway—one powered not by bigger furnaces alone, but by smarter data. Artificial intelligence is helping steelmakers rethink how they produce, inspect, move, and sustain steel, turning one of the country's most traditional industries into a more agile, efficient, and future-ready sector. Across major players such as Tata Steel, JSW Steel, and SAIL, AI is no longer a fringe experiment. It is becoming central to how plants operate, how

decisions are made, and how companies compete in a rapidly evolving industrial landscape.

Smarter Plants

One of the clearest signs of this shift is on the shop floor. Steelmaking has always involved managing thousands of variables at once—temperature, pressure, raw material mix, fuel efficiency, and output quality. AI systems can process this complexity in real time, spotting patterns that human operators might miss and suggesting changes that improve yield and consistency. Digital twins, or virtual replicas of production lines, make this even more powerful by allowing teams to test scenarios before implementing them in live operations. The result is a move away from reactive production toward continuously optimized manufacturing.

Less Downtime

Maintenance is another area where AI is delivering immediate value. In steel plants, equipment downtime is expensive and disruptive, especially in continuous operations where even short stoppages can ripple across production schedules. By combining sensor data with machine learning, companies can detect early warning signs of wear or failure and act before breakdowns occur. Some implementations have reported equipment failures dropping by up to 35 percent, while companies such as Tata Steel and JSW Steel are using AI-led monitoring to extend asset life, reduce shutdowns, and make maintenance planning far more precise than traditional schedules allowed.

Better Quality

Quality control, historically dependent on manual inspection and post-production checks, is also being redefined. Computer vision systems can now scan steel surfaces in real time and detect defects with far greater speed and consistency. That means fewer rejections, more uniform product quality, and stronger compliance with international standards. For an industry competing in global markets, that consistency matters. AI is helping manufacturers reduce variability and move toward a model where quality is built into the process rather than checked at the end.

Greener Steel

Perhaps even more importantly, AI is strengthening the industry's sustainability agenda. Steelmaking is energy-intensive and carbon-heavy, so even modest improvements in fuel use, raw material efficiency, or emissions tracking can have a significant impact. AI models are increasingly being used to optimize energy

consumption, align production with decarbonization goals, and support India's broader push toward green steel. In a market where environmental performance is becoming as strategic as production capacity, intelligent systems are emerging as a crucial bridge between profitability and sustainability.

Smarter Supply

Beyond the furnace, AI is improving the broader steel value chain. Forecasting tools help companies anticipate demand more accurately, while AI-driven inventory systems reduce both overproduction and shortages. Logistics can be optimized to improve raw material flow and delivery scheduling, helping steelmakers respond faster to market changes. In a sector where margins depend not only on production but on timing, movement, and working capital, this kind of visibility can create a major competitive edge.

Safer Floors

Safety, too, is being reshaped by intelligent systems. Steel plants are hazardous environments, and AI-based monitoring can help detect unsafe behavior, missing protective equipment, or early indicators of risk. Instead of relying solely on retrospective reports, companies can use pattern analysis to identify where incidents are more likely to occur and intervene proactively. This shift from reactive safety management to predictive risk prevention has the potential to make shop floors not only more compliant, but measurably safer.

Faster Decisions

Underpinning all of this is a new culture of data-driven decision making. Integrated dashboards and command centers now give plant leaders real-time visibility into production, maintenance, procurement, and performance. Instead of waiting for reports, managers can act on live operational intelligence. That shift is subtle but transformative: AI is not just automating tasks, it is changing the speed and quality of decisions across the enterprise.

The Transition

The transition is not without friction. Many plants still operate with legacy infrastructure, implementation costs remain high, and the shortage of AI-skilled talent continues to slow adoption. Success will depend not only on technology investments, but also on integration, training, and leadership commitment. The winners are likely to be the companies that treat AI not as a side initiative, but as part of their long-term operating model.

The Road Ahead

What is happening in India's steel sector is a reminder that even the most traditional industries can be reinvented. AI is not replacing the fundamentals of steelmaking; it is making them sharper, safer, cleaner, and more responsive. And as adoption deepens, the steel plant of the future is becoming easier to imagine: less a heavy industrial black box, and more an intelligent factory built for performance, resilience, and sustainable growth.

Source: ARC Advisory Group, June 10, 2026

China's AI Steel Hub

China has launched a national artificial intelligence application pilot base for the metallurgical sector in Nanjing, marking a significant step in its efforts to integrate AI into one of the country's largest manufacturing industries. The initiative is designed to accelerate the adoption of AI technologies across steel production and related metallurgical operations.

Bridging research and industrial deployment

The new pilot base is expected to serve as a bridge between AI research and large-scale industrial implementation. The facility will focus on building industry datasets, developing specialised AI models, creating toolchains and establishing pilot testing platforms that can help move technologies from the laboratory to production environments.

The project aims to address one of the key challenges facing industrial AI adoption, namely the gap between *proof of concept applications* and *deployment at commercial scale*. By providing a dedicated testing and validation environment, the base is expected to support the development of solutions tailored to steelmaking processes and metallurgical operations.

China's steel industry remains the world's largest, and the sector has increasingly adopted digital technologies to improve productivity, quality control and operational efficiency. AI applications are already being explored in areas such as predictive maintenance, process optimisation, energy management and production planning.

Part of China's wider AI strategy

The launch aligns with China's broader policy push to accelerate AI deployment across manufacturing industries. The country has repeatedly highlighted artificial

intelligence as a key driver of industrial upgrading and technological self reliance, with policymakers encouraging the integration of AI into traditional sectors.

The initiative as part of a wider effort to strengthen the competitiveness of Chinese manufacturing through advanced technologies. Beyond steel production, the pilot base could provide a framework for applying AI across other heavy industries where operational complexity, energy consumption and process efficiency remain critical priorities.

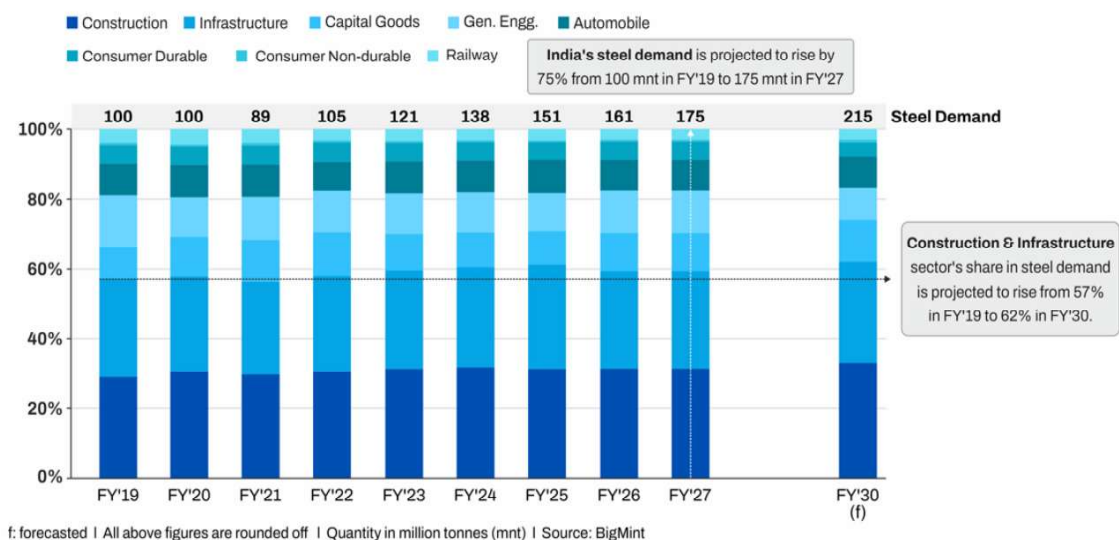
As manufacturers worldwide explore the role of AI in industrial operations, China's latest move underscores the growing importance of sector specific innovation platforms that can help translate emerging technologies into practical manufacturing applications.

Source: Manufacturing Today, Digital Transformation, 17 June 2026

India's Sector - wise Steel Demand

India's finished steel consumption rose 7% y-o-y to 161 million tonnes (mnt) in FY'26, recording the slowest growth in the post-pandemic era and slightly lower than the 9% increase recorded in 151 mnt in FY'25.

This followed a marked shift in the composition of India's steel demand, with infrastructure-linked consumption remaining stagnant y-o-y at 45 mnt. In comparison, manufacturing-linked sectors gained share, accounting for over 70% of the 10 mnt increase in steel demand.



Sector-wise steel demand

India's sector-wise steel consumption in FY26

Construction demand accelerates

Construction remained India's largest steel-consuming sector and contributed the biggest increase in demand during FY'26. Consumption rose 8.5% y-o-y to 51 mnt, adding around 4 mnt of incremental demand.

The housing market remained relatively supportive. New residential supply across 75 tracked cities rose 10% y-o-y despite a slight 1% decline in sales, indicating developers remained confident about medium-term demand.

Infrastructure-linked growth stalls

In contrast, infrastructure-linked steel demand remained stagnant, as slower project execution, rather than a lack of budgetary support, weighed on the sector. Key challenges included delays in land acquisition, slower project awards, moderation in highway construction and Jal Jeevan Mission implementation, delayed contractor payments, and slower fund disbursement cycles.

For example, national highway construction fell to around 9,380 km in FY26, missing the government's 10,000 km target and marking the lowest level since FY18. Highway project awards also declined, reducing the pipeline of steel-intensive construction activity.

Execution challenges were also evident at the state level. By February 2026, 22 states had utilised only around 55% of their combined capital expenditure budgets for FY26, indicating a significant lag between budget allocations and on-ground project implementation.

Steel demand from both the construction and infrastructure sectors grew at double-digit rates between FY22 and FY24, driven by a post-pandemic recovery in construction activity, accelerated execution of government infrastructure projects, and a sharp increase in public capital expenditure. However, this momentum weakened from FY25 as project execution slowed.

Manufacturing sector takes over as growth driver

While infrastructure lost momentum, manufacturing-linked demand strengthened. Manufacturing-linked steel demand strengthened significantly in FY'26. Combined steel demand from general engineering, capital goods, consumer durables, and automobiles rose to 60 mnt in FY26 from 53 mnt in FY25.

India's manufacturing GVA growth accelerated to around 11.5% y-o-y in FY26 from 9.3% in FY25, according to World Bank data. Private consumption grew 7.7% y-o-y

in FY26, accelerating from 5.8% in FY25, aided by rising household income, lower inflation, income tax relief, and GST rationalisation.

Moreover, investment growth accelerated due to higher private spending on manufacturing plants and equipment alongside continued public capital expenditure.

The favourable demand and investment environment contributed to stronger steel consumption in the general engineering, capital goods, and consumer durable sectors.

Engineering, capital goods momentum strengthens

The engineering sector alone contributed around 3 mnt of incremental steel demand during FY26. Notably, India's engineering exports rose 5% y-o-y to an all-time high of approximately \$122 billion in FY26, accounting for nearly 28% of the country's merchandise exports.

Steel demand from the capital goods sector increased 20% y-o-y to 18 mnt in FY26, coinciding with stronger manufacturing investment and expansion in machinery and equipment production. According to the governments Index of Industrial Production (IIP), capital goods output growth accelerated to 11.7% y-o-y in FY26 from 9.3% y-o-y in FY25.

Consumer durables also contributed modestly, with steel demand rising to 8 mnt as appliance manufacturers continued to expand domestic production and localisation.

Notably, manufacturing activity benefited from the governments Production-Linked Incentive (PLI) programme, which has attracted cumulative investments of INR 2.4 lakh crore by the end of FY26.

Significant investments flowed into solar photovoltaic modules, automobiles and auto components, and white goods, supporting demand for machinery, engineering products, and industrial facilities.

In the power segment, India also added a record 55.3 GW of non-fossil fuel-based capacity during FY'26, with the volume nearly doubling y-o-y.

Record sales fail to lift auto sector steel consumption

Strikingly, steel demand from the automobile sector remained unchanged at 15 mnt in FY26 despite record vehicle production and sales. Total vehicle production increased 11.8% y-o-y to 347 million units, while domestic sales rose 10.4% to 28.3 million units, according to Society of Indian Automobile Manufacturers (SIAM).

The growth in sales was heavily concentrated in two-wheelers, which accounted for nearly 80% of incremental vehicle sales during the year. Two-wheeler sales rose by 2.1 million units, while passenger vehicle sales increased by only 342,000 units and commercial vehicle sales by 123,000 units. Since two-wheelers consume significantly less steel per unit than passenger vehicles and commercial vehicles, the increase in overall vehicle volumes possibly did not translate into proportionate growth in steel demand.

Moreover, automotive steel demand had already rebounded strongly between FY'22 and FY'25, limiting the scope for further gains.

Steel demand from railways remains stable

The railways sector contributed 5 mnt of steel demand in total in FY26, stable y-o-y. Demand remained supported by sustained investment in network expansion, track doubling, electrification, rolling stock procurement, station redevelopment, and Dedicated Freight Corridor (DFC) projects. Notably, Indian Railways fully utilised its record capital expenditure

Outlook

India's finished steel consumption to rise 8% y-o-y to 175 mnt in FY'27. The main change from FY'26 is likely to be the return of infrastructure as a growth driver. Steel demand from the sector is projected to increase to 49 mnt as project execution improves and large public investment programmes gain traction.

Construction sector demand is expected to remain robust, rising to 55 mnt, supported by housing and urban development activity. However, although manufacturing-linked sectors should continue to grow, the pace will slow, with the sector contributing 5 mnt to incremental steel demand. This follows concerns over slower economic growth, shrinking discretionary spending, and softer rural demand due to the West Asia crisis and a weak monsoon.

The result would be a broader-based demand recovery, with construction, infrastructure, and manufacturing once again expanding in tandem.

Source: Bigmint updates, 23 Jun 2026

India's Stainless Steel Production

The country's stainless steel production stands at 5.16 million tonnes, compared with the global total of 64.2 million tonnes. While against the world average of 6 kg, the per capita consumption of stainless steel is around 3.4 kg in India.

Red Mud to be Aluminium Industry's Next Resource Frontier

For decades, the aluminium industry has lived with a structural contradiction: for every tonne of alumina produced, it generated up to 1.5 tonnes of highly alkaline waste - Red Mud. With global alumina output crossing 141 million tonnes in 2023 and 154 million tonnes in 2025, annual bauxite residue generation has already exceeded 175 million tonnes. The cumulative stockpile stands at an estimated 4 billion tonnes, making it one of the largest untapped secondary mineral reserves on the planet.

Red mud, long treated as a disposal liability due to its pH of 10-13 and contamination risks, is now being re-evaluated as a multi-metal resource containing iron, alumina, titanium, silica, and, critically, scandium, gallium, and rare earth elements.

Residue composition varies sharply across geographies, but the underlying opportunity is consistent. Iron oxide content ranges from 28.5 per cent in some Australian refineries to as high as 56.9 per cent, while Indian residues at Damanjodi report around 53 per cent Fe_2O_3 . Alumina content typically sits between 15 per cent and 24 per cent, with silica and lime levels dictating downstream usability.

That variability is no longer a barrier. High-iron residues in India and Australia are being positioned for metallurgical recovery. In contrast, China's sintering-derived residues, containing up to 41.6 per cent CaO and 32.5 per cent SiO_2 , are being directly integrated into cement production, bypassing costly pre-treatment.

Impact of the trace element level

Scandium concentrations in red mud range from 45 to 150 ppm — more than double the Earth's average crustal abundance. Gallium levels reach up to 200 ppm, while vanadium can approach 800 ppm. Rare earth elements such as cerium and lanthanum further strengthen the case.

Technology is catching up with ambition

The most disruptive development has been the commercial scaling of *Flash Joule Heating (FJH) with chlorination*. The process compresses what was once an energy-intensive, multi-stage operation into a 60-second reaction, extracting more than 96 per cent of iron while retaining 99 per cent of aluminium in the residue. It simultaneously removes sodium and volatilises toxic metals, addressing both recovery and environmental challenges in a single step.

Hydrometallurgical systems are evolving in parallel, with staged acid leaching now achieving around 90 per cent recovery of iron and aluminium, followed by selective precipitation that delivers over 95 per cent iron recovery and up to 80 per cent recovery of rare *earths*. A 2025 breakthrough using *ammonium sulfate roasting* has further improved scandium extraction while keeping iron dissolution below 0.12 per cent, significantly improving selectivity.

Meanwhile, high-volume recovery is moving into industrial scale. In Brazil, a project scheduled for completion in mid-2026 will process 50,000 tonnes of residue annually to produce 9,000 tonnes of pig iron and 22,000 tonnes of construction materials. In China, combined roasting technologies are already delivering iron recovery rates above 93 per cent alongside aluminium purity of 99.49 per cent.

Biobleaching long considered experimental, is beginning to show economic viability. Recovery rates of 70 per cent for terbium and 60 per cent for gadolinium within three days, combined with capital costs as low as USD 30-50 million per million tonnes of capacity, are positioning it as a viable low-energy alternative.

India is building a hybrid model. A 10-tonne-per-day pilot is targeting simultaneous recovery of iron, alumina, and scandium, while converting residual material into construction bricks, potentially 1 million units annually. With the country's construction sector projected to reach USD 1.4 trillion by 2047, the demand-side pull is already in place.

China is scaling through mandate. With over 100 million tonnes of residue generated annually, Beijing has set utilisation targets of 15 per cent by 2027 and 25 per cent by 2030, backed by multi-billion-yuan investments in clinker and materials production.

Europe is leaning on decarbonisation. Projects such as *ReActiv* have demonstrated that bauxite residue can replace up to 30 per cent of cement clinker, cutting emissions by a similar margin while reducing landfill dependence.

The United States, in contrast, is framing the issue through national security. Federal funding is now directly targeting the recovery of gallium and scandium, aiming to rebuild domestic supply chains that have been absent for decades.

The global red mud processing market, valued at USD 116.51 million in 2024, is projected to reach USD 171.09 million by 2032, growing at 4.92 per cent annually. But the real economics lie beneath that headline number.

Iron recovery alone could yield between 45 and 90 million tonnes annually at prices of USD 90-120 per tonne. Alumina recovery adds another 15-30 million tonnes at USD 250-400 per tonne. Gallium output, though smaller in volume, could reach up to 30,000 tonnes, commanding strategic premiums.

Layer in avoided disposal costs of USD 5-15 per tonne and carbon credits of USD 20-60 per tonne of CO₂ equivalent, and the financial logic begins to shift decisively from cost centre to revenue stream.

What is emerging is not a marginal efficiency gain. It is a structural rewrite of the alumina value chain.

The industry is moving towards full-spectrum valorisation — neutralising residue, extracting bulk metals, refining critical minerals, and converting the remainder into construction-grade materials. In this model, waste does not exist. Only underutilised feedstock does.

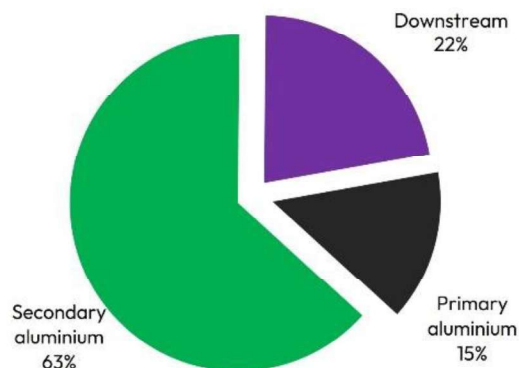
The implication is clear

With 150 million tonnes of new residue added every year, the recalibration is no longer optional. It is becoming central to how the industry competes.

Source: AL CIRCLE, 05 May 2026

Aluminium Dross Processing: Generation, Recovery and Strategic Roadmap

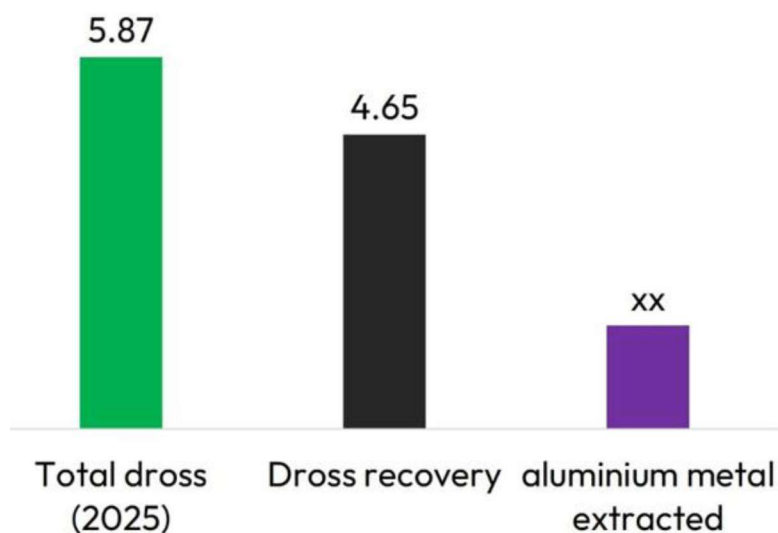
Aluminium dross is no longer just a waste-management issue. As primary aluminium production, secondary recycling and downstream processing expand, dross generation is becoming a serious cost, compliance and recovery challenge for recyclers, smelters, cast-houses, foundries and downstream manufacturers. In 2025, secondary aluminium production alone generated 63 per cent of total dross worldwide, followed by the downstream sector accounting for 22 per cent and primary aluminium 15 per cent.



Dross Generation By Sector, 2025 (in %)

Why industry stakeholders cannot ignore aluminium dross anymore

The aluminium industry is accelerating its transition towards recycling-led and low-carbon production models. While this is to lower the carbon footprint in the environment, on the way comes a growing operational challenge, including increasing volumes of black dross, salt slag and complex residue streams generated across the aluminium value chain. In the absence of adequate treatment and recovery infrastructure, the industry risks transforming a circular-economy opportunity into a larger waste-management and compliance concern.



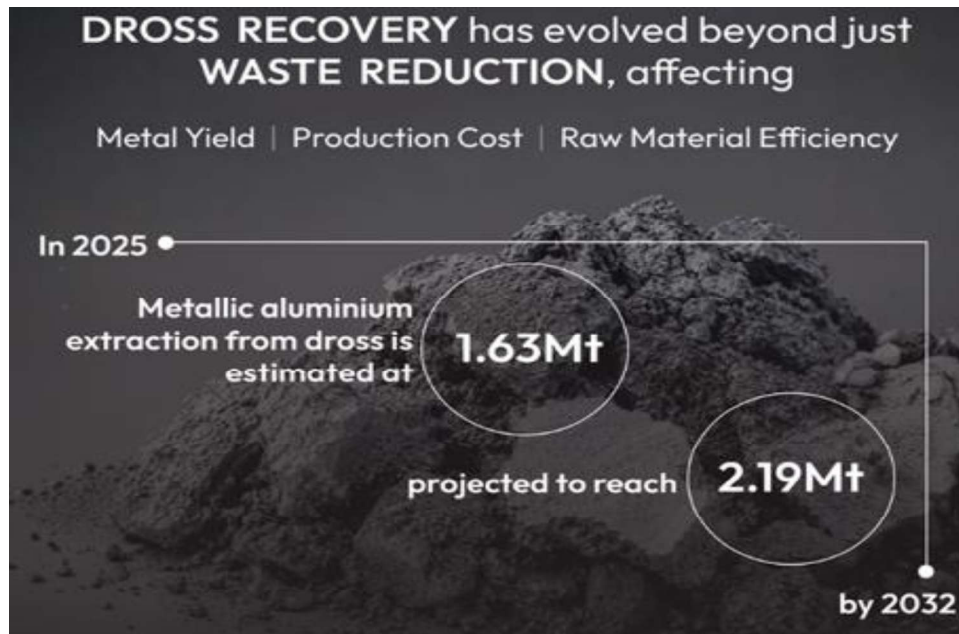
Global aluminium dross generation, recovery & metal extraction, 2025 (in mt)

Strategic insights into the evolving economics of aluminium dross recovery, commercially viable processing technologies, regional market developments and emerging residue utilisation pathways have been drafted in this report. It further evaluates how recovered dross materials are being positioned across cement, construction, refractories, ceramics, flux recovery and speciality industrial applications.

Category	Volume
Total dross (2025)	5.86771
Dross recovery	4.649667
Aluminium metal extracted	1.62738345

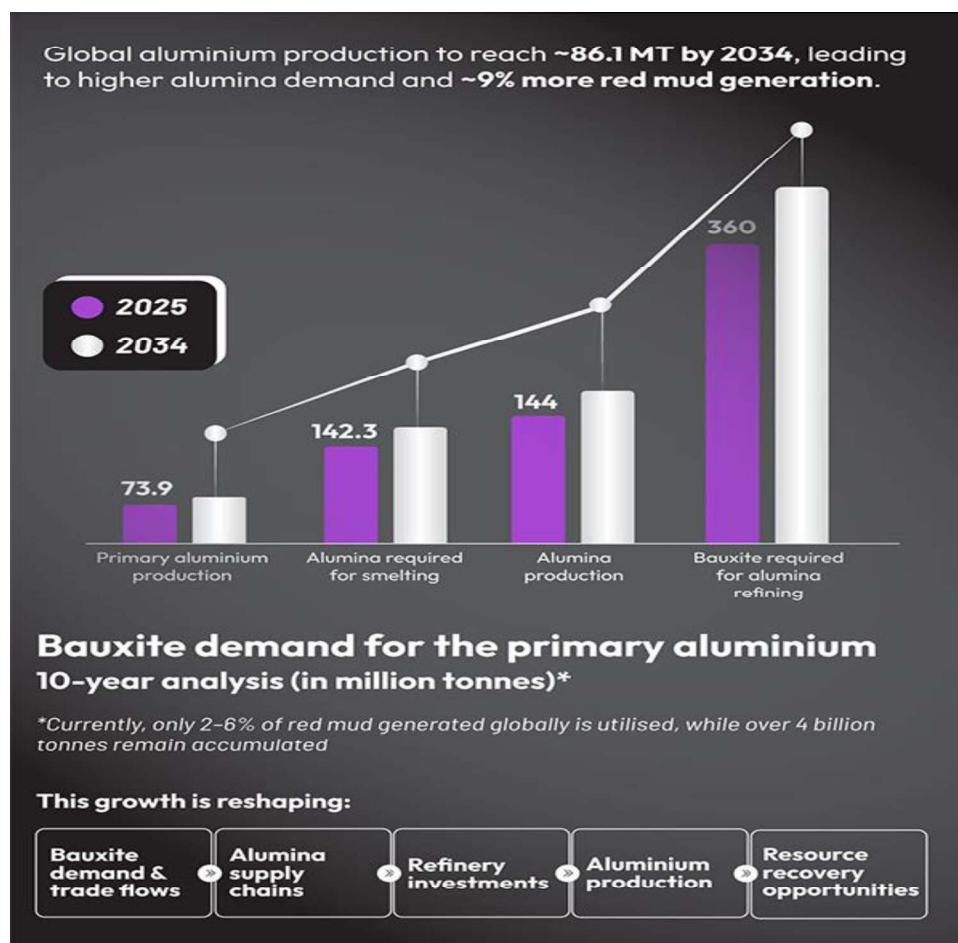
Sector	Dross Generation
Primary aluminium	0.84985
Secondary aluminium	3.723
Downstream aluminium	1.29486

Critical market insights shaping the future of aluminium dross



Top 5 regions: Dross recovery in 2025 (in 000 tonnes)
Global Metal Extraction Rate (Avg): 34% to 36%

Region	Dross Recovery	Demand Drivers	Market Projection
China	2165.13	• New smelters • Secondary aluminium projects • Scrap consumption • High remelting activities	High growth potential
ROAP (Rest of Asia Pacific)	855.41	• New smelters • Capacity expansions • Recycling growth • Downstream investments	High-growth market
North America	579.84	• New smelters • Higher recycled aluminium production	High growth with high risks
Europe	568.65	• Higher recycling intensity • Strict environmental compliance • Growth in recycled aluminium production	High growth projected
South America	195.47	• Rising recycling activity • Higher downstream product demand	Moderate growth projected



Source: AL Circle Newsletters 22 Jun 2022

Aluminum-Lithium Alloys

Aluminium-lithium (Al-Li) alloys are becoming increasingly critical for reducing fuel consumption and weight in commercial aviation. Over the next five years, the evolution of aluminium–lithium (Al-Li) alloys in India will be shaped by a demand-led acceleration anchored in aviation sustainability goals, while production will follow a more gradual, capability-building trajectory. The interplay between these two will define India’s position as a high-growth consumption market with emerging, but still maturing, domestic supply capabilities.

From a demand standpoint, the outlook is strongly positive. Globally, the aviation Al-Li alloys market is expanding at roughly 7–9 per cent CAGR, driven by the aerospace industry’s shift toward lightweight materials that improve fuel efficiency and reduce emissions. This trend is even more pronounced in emerging aviation markets such as India, where rapid growth in air travel and fleet expansion is underway. Asia-Pacific, including India, is expected to account for a significant share

of future aircraft demand, creating a strong pull for advanced materials like Al-Li alloys.

In the Indian context, this translates into a 10–12 per cent CAGR in Al-Li alloy demand over the next five years, implying that total consumption could increase by ~1.7–2.2x within this period. The primary driver will be commercial aviation, which will account for roughly 70–75 per cent of demand, as airlines increasingly adopt next-generation aircraft designed for lower fuel burn. Al-Li alloys enable ~8–10 per cent weight reduction compared to conventional aluminium, directly translating into fuel savings and lower carbon emissions. As sustainability commitments tighten—both globally and within India—airlines and OEMs will accelerate the substitution of traditional materials with Al-Li alloys in fuselage structures, wing components, and other critical applications.

Defence aviation will contribute an additional 15–20 per cent of demand, supported by India's ongoing indigenisation efforts and modernisation programs, while space and advanced aerospace applications will account for 5–10 per cent, reflecting high-value but lower-volume usage.

Over the next five years, India's Al-Li alloys market will be characterised by strong demand growth (10–12 per cent CAGR, ~2x increase), driven predominantly by commercial aviation sustainability needs, alongside moderate but strategic production expansion (~2–3x from a low base). India will remain import-dependent in the near term but will steadily build capabilities in downstream processing and component manufacturing, positioning itself as an emerging participant in the global Al-Li aerospace materials ecosystem rather than a fully integrated producer.

Source: AL Monthly Newsletter, 20 Jun 2026

Commitments for Recycling Critical Minerals Scheme Treble

India's efforts to build a domestic ecosystem of critical minerals have received a boost, with commitments under the government's Rs. 1500 crore recycling scheme reaching 850 kilo tonnes per annum (ktpa) against a largest of 270 ktpa.

Another scheme to develop a domestic value chain of processing battery minerals is nearing finalization. The scheme could generate an annual capacity to recycle 300,000 tonnes of e-waste by 2030, he said. The recycling scheme, launched under the National Critical Mineral Mission, has approved 58 recyclers and expected to help India emerge as a major global hub for critical-mineral recycling by 2030.

The programme incentivizes recovering 27 critical minerals, with benefits linked to mineral extraction and processing rather than black mass production. Alongside recycling, the government is moving to address a gap in the supply chain of critical minerals. The ministry was close to finalizing the scheme for battery minerals after six rounds of stakeholder consultations.

Indian companies hold critical mineral assets overseas. They include lithium and cobalt resources in Africa and elsewhere, but the lack of processing infrastructure in the country has limited value addition here.

The government is accelerating domestic exploration and mining. While the target is 1200 exploration projects by 2031, the ministry expected the number to exceed 2000, supported by greater participation from private exploration agencies. So far 571 projects have been completed and another 300 are expected to be completed this year. In mining, India in FY26 auctioned a record 212 mineral blocks and operationalized 36 mines. They include 28 greenfield projects. The Centre is aiming to operationalize 50-60 greenfield mines in FY27.

Global Energy Consumption Continued to Rise in 2025

Many types of energy met global demand last year. Oil, natural gas and coal continued to play the biggest roles, accounting for almost 80% of total energy supply. Low-emissions sources – renewables and nuclear – accounted for around 20%.

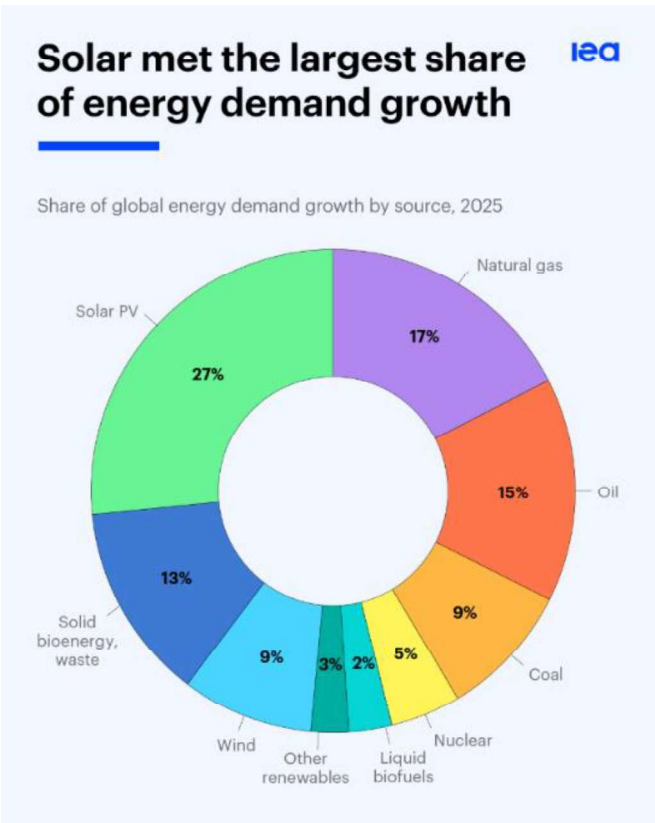
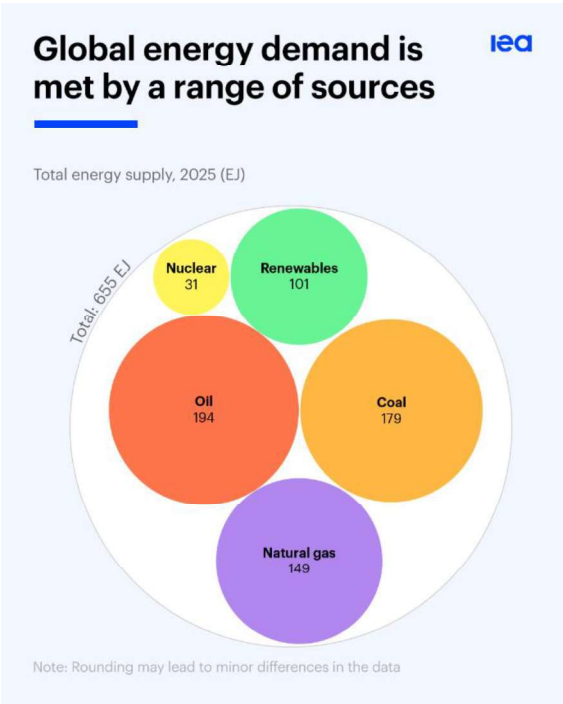
Global energy demand rose by 1.3% in 2025 (a smaller rise than in 2024 but in line with the previous decade's average). To meet this increase, all major fuels and technologies expanded.

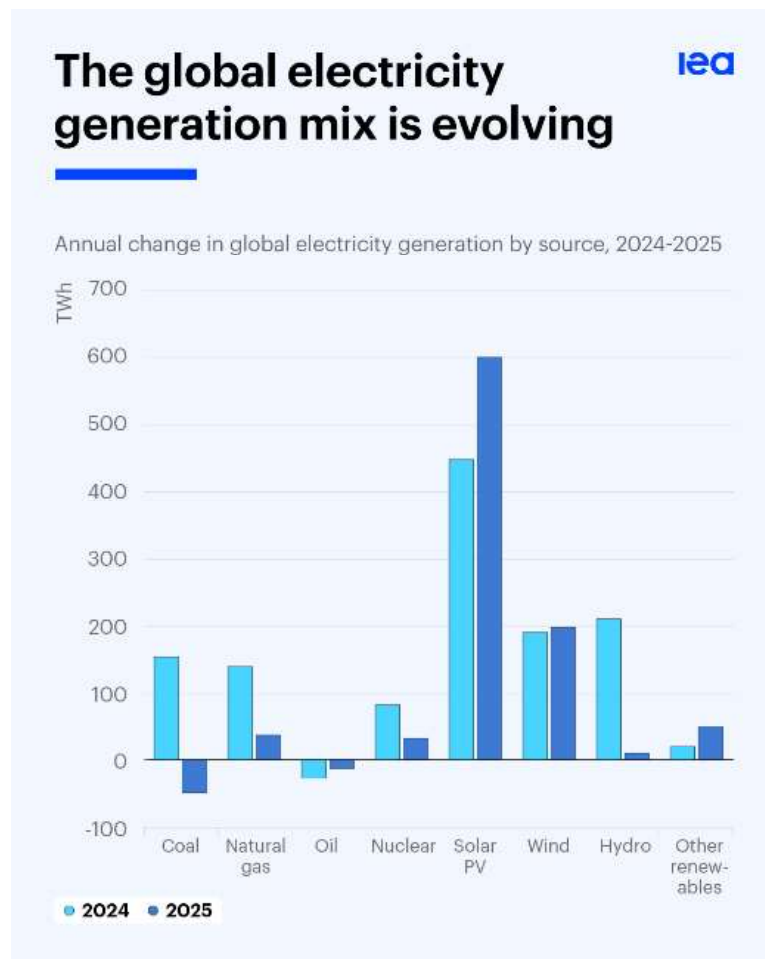
The trends indicate that changes to the global energy mix are gathering pace. One energy source grew much faster than the others: solar PV. It met 27% of the world's energy demand growth in 2025 – the first time a modern renewable source covered the largest portion of growth. Natural gas covered the next largest share, at 17%, reflecting its big role in power generation in many countries. Overall, renewable sources and nuclear met nearly 60% of all growth in energy demand in 2025.

The strong contributions of low-emissions sources in meeting rising demand was particularly visible in the electricity sector, where annual consumption increased by 3% – more than twice as fast as overall energy demand.

Renewables – led by the boom in solar capacity – accounted for the vast majority of growth in global electricity generation to meet rising demand. At the same time, the

amount of electricity produced from both coal and oil declined while the amount generated from natural gas increased modestly.





As a result, total electricity generation from renewables – which include hydropower, solar, wind, geothermal and bioenergy – virtually matched that from coal in 2025 on a global level.

Source: IEA Energy Snapshot, 11 May 2026

India is Likely to Witness a 4–6x Increase in Critical Mineral Consumption by 2040

The recent amendments to India’s mining concession rules represent a structurally significant shift from a restrictive licensing regime to a more facilitative, production-oriented framework for critical minerals. These changes are expected to enhance domestic output and strengthen India’s positioning in the global critical minerals value chain through multiple reinforcing mechanisms.

The amendments directly address one of the most persistent bottlenecks in India’s mining sector - fragmented and underutilised mineral deposits. By allowing existing leaseholders to expand into contiguous areas (up to ~10 per cent for mining leases

and ~30 per cent for composite licences), the policy enables more efficient resource extraction and reduces the need for fresh auctions and approvals. This not only accelerates project timelines but also improves geological continuity, thereby increasing the economic viability and output potential of existing mines.

In addition, the introduction of simplified and time-bound approval processes significantly enhances ease of doing business. Faster approvals reduce regulatory uncertainty and holding costs for mining firms, which in turn incentivises higher capital deployment in exploration and extraction of deep-seated and critical minerals. This is particularly important for minerals such as lithium, cobalt, rare earth elements, and nickel, where exploration risks and long gestation periods have historically deterred private investment.

Thus, the amendments are likely to drive (i) faster capacity expansion through lease optimisation, (ii) higher exploration and investment inflows, (iii) improved recovery and efficiency, and (iv) stronger supply chain security. Collectively, these outcomes position India to significantly enhance its critical minerals output and gradually strengthen its competitiveness and strategic relevance in the global market.

India's demand for critical minerals is set to rise sharply by 2040, driven by the country's accelerating energy transition, industrial electrification, and digital expansion. In aggregate terms, India is likely to witness a 4–6x increase in critical mineral consumption by 2040, translating into an estimated 8–12 per cent CAGR over the next 15 years. This growth will not be uniform across minerals. Battery-linked minerals such as lithium, nickel, and graphite are expected to grow at the upper end of this range (or higher), while base transition metals such as copper and rare earth elements will see relatively moderate but still substantial expansion.

On the supply side, India's domestic production is expected to grow meaningfully but at a slower pace than demand. With recent policy reforms—particularly the expansion of mining leases, improved exploration incentives, and the push under the National Critical Mineral Mission—India could achieve 3–5x growth in domestic production by 2040, with an upside scenario of 5–7x if execution remains strong and private/global participation scales up.

However, given the current near-total import dependence for several key minerals (notably lithium, cobalt, and nickel), India is unlikely to achieve full self-sufficiency. Instead, it will evolve into a hybrid model—partially self-reliant in mining, but increasingly strong in processing, refining, and recycling, thereby securing a more strategic position in global supply chains.

India's critical minerals landscape by 2040 will be characterised by demand outpacing supply, with consumption growing 4–6x and production scaling up 3–5x.

The demand will be overwhelmingly driven by the twin engines of electrification (EVs and storage contributing ~ 60–65 per cent) and renewable energy (~ 15–20 per cent), reinforcing India's emergence as a major global demand center and an increasingly important node in the downstream processing and supply chain ecosystem.

The production of critical minerals is responsible for 4 to 8 per cent of global greenhouse gas emissions. The paradox at the heart of the energy transition is that while critical minerals are indispensable for clean technologies, their extraction and processing are themselves carbon-intensive -accounting for an estimated 4–8 per cent of global greenhouse gas emissions. In response, both global stakeholders and India are increasingly pursuing a multi-pronged decarbonisation strategy across the mining and minerals value chain, combining technology shifts, policy interventions, and circular economy approaches.

The global and Indian response to emissions from critical mineral production is converging around four key levers: (i) electrification and renewable-powered mining, (ii) low-carbon processing technologies, (iii) circular economy and recycling, and (iv) stronger ESG and policy frameworks. While the sector's emissions are likely to rise in absolute terms due to surging demand, these measures are expected to significantly reduce emissions intensity per unit of mineral produced, enabling the industry to support the energy transition without undermining its climate objectives.

Red mud, containing between 0.5 to 1.7 kg per tonne of total rare earth elements (REEs), is a significant byproduct of the alumina refining process. The Current situation indicates that about ~ 8–10 MTPA red mud is generated per annum in India having REE content 0.5–1.7 kg/tonne. As on date, commercial REE extraction is almost nil, the activity is limited to research and pilot stage. **Core Challenges in extraction of REEs from red mud are :**

Technical: Low grade, complex mineralogy, high alkalinity

Economic: High processing cost vs cheaper imports

Ecosystem: Lack of policy push, weak commercialisation pipeline

India Can Unlock Value from red mud by

1. Pre-concentration + selective extraction (focus on Scandium, high-value REEs)
2. Cluster-based processing hubs near alumina refineries
3. Policy incentives + critical minerals alignment (PLI, VGF, mandates)
4. Multi-product recovery model (REEs + Fe + Ti + cement use)
5. PPP-led scale-up (R&D → pilot → commercial)

China is responsible for 95 per cent of global rare earth output and supplies a lion's share to the world. India has been dependent on China for 90 to 93 per cent of its

rare earth magnets until FY2025. To reduce dependence on China, India has launched many strategic initiatives.

India's efforts to reduce its overwhelming dependence on China in the rare earths and magnet value chain are directionally strong and strategically well-aligned, but their success will be gradual rather than immediate, given the structural complexity of this sector. The reality is that while policy intent has sharply accelerated, capability creation in rare earths—especially magnet manufacturing—operates on long gestation cycles (5–10+ years).

At present, India's dependence - estimated at 90–93 per cent of rare earth magnet imports until FY2025 - is not merely a supply issue but a reflection of deep-rooted structural gaps. These include limited domestic separation and refining capacity, negligible magnet manufacturing scale, lack of integrated value chains, and relatively weak downstream demand aggregation compared to China's massive industrial ecosystem. Therefore, any assessment of India's strategic initiatives must recognise that the country is effectively building an ecosystem from scratch, rather than incrementally upgrading an existing one.

India's initiatives will be moderately successful in the short term, materially impactful in the medium term, and strategically transformative over the long term, with a realistic timeline of 8–12 years to achieve meaningful supply chain independence and global relevance in rare earth magnets.

The global push toward clean energy, electrification and digital infrastructure has firmly established critical minerals as the backbone of future economic growth. However, while demand is accelerating, the policy ecosystem governing their production, processing, and usage remains uneven and, in many regions, insufficiently aligned with long-term transition goals. Both globally and in India, the next phase of progress will depend not just on increasing supply, but on creating a coherent, end-to-end policy architecture that stimulates demand, ensures sustainability, and de-risks investments across the value chain.

Increasing the usage of critical minerals globally—and in India—requires a holistic policy approach that goes beyond mining to encompass the entire lifecycle of materials. This includes stable investment frameworks, value-chain integration, recycling ecosystems, sustainability standards, and international collaboration. For India specifically, the focus must be on creating domestic demand pull, building processing capabilities, and securing diversified supply sources. Only through such coordinated and forward-looking policies can countries ensure that critical minerals truly enable, rather than constrain, the global energy transition.

Source: AL Monthly Newsletter, 20 Jun 2026