



IIM

Metallurgy
Materials Engineering

The Indian Institute of Metals-Delhi Chapter

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Formation of IIT Delhi Student Chapter

As desired by Prof. BS Murty, President, The Indian Institute of Metals (IIM) and Director, Indian Institute of Technology, Hyderabad, a program was held for formation of IIM Student Affiliate Chapter at the Indian Institute of Technology (IIT) Delhi, on 21.4.2026.

Prof. Jayant Jain, Head of the Department of Materials Science and Engineering (DMSE), IIT Delhi, welcomed Prof. B S Murty, Shri L Pugazhenthay, Past President of IIM and Executive Director, India Lead Zinc Development Association, members of Executive Committee of IIM Delhi Chapter, faculty and students.

In his address, Prof. B S Murty briefed about IIM and privilege, advantages and benefits of joining Student Affiliate Chapter of IIM.



The Indian Institute of Metals (IIM) was set up in 1946 with 42 members. Now the IIM membership is around 11000. The main objective of IIM is to promote metallurgical activities in India. Affairs of the IIM are managed by the National Council consisting of 60 eminent members representing industry, academia and R&D organizations including Defence, Atomic and Nuclear establishments. The activities of IIM are carried out by its various Chapters spread pan India.

There is no joining or membership fee for undergraduate, post graduate and Ph.D. students for joining Student Affiliate Chapter of IIM.

Annual Technical Meeting (ATM) is the flagship event of the IIM which is held every year at different places in the country, organized by local IIM Chapter. About 1800

delegates participated and about 1000 papers were presented in the last ATM held at Hyderabad in December 2025.

From this year IIM is also starting a mini ATM event. It will be free for students. All the arrangements for students will be made by IIM except travel cost. Prof. Murty mentioned that IIM has requested the academic institutions where Metallurgy/Materials Department is there, to nominate two students for the ATM and one of the them should be a female student. The ATM platform shall provide an excellent opportunity to students for interaction with CEOs of big companies.

IIM also arranges internship programmes for students. About 100 students have been selected this year for internship programme.

Prof. Murty also talked about start-up support for students. This year 3-5 grants will be given for start-ups initiated by students.

IIM is also starting mentorship programme for students.

Prof. Murty informed that IIT Hyderabad is starting B. Tech programme on semi-conductors and also Master's programme on Packaging, M. Tech. Programme on critical minerals extractive metallurgy is also being started at IIT Hyderabad.

He stated that in the last 2-3 months about 20 student Chapters have been set up by IIM. He opined that every college with metallurgy/materials department should have a Student Affiliated Chapter of IIM.



The major activities of Student Affiliated Chapter include holding workshops on metallurgy, materials science and manufacturing, conduct seminar/conferences awareness programmes, quiz on metallurgy/materials science etc. The concerned IIM Chapters shall extend all support for these activities. Financial support shall also be extended by IIM Head Office to Student Affiliated Chapters to hold such programmes. IIM Students Chapter at IIT Delhi will be affiliated to IIM Delhi Chapter. IIM Delhi Chapter can help the students in connecting with industry. He

advised IIM Delhi Chapter that they should also invite students in their programmes. Student members should also be inducted in the Executive Committee of the Chapter.



Global Excess Steel Capacity

There is continued deterioration in market conditions, driven by the unsustainable growth in global steel excess capacity. China's share of global excess capacity rose during 2025, surpassing 50% in the latter part of the year, spurring surges of exports to international markets. This excess capacity is putting enormous pressure on international markets by driving prices and industry profitability down. These headwinds are also impeding the steel industry's ability to invest in innovation and lower-carbon production.

Global steel demand has contracted for four years in a row, with the rate of decline accelerating to more than 2% in 2025. Projections for 2026 indicate modest global demand growth, though the extent of the impacts of the current conflict in the Middle East on global steel markets is highly uncertain. While demand in China is expected to continue its structural decline, albeit at a more moderate pace compared to the estimated 6.5% contraction observed in 2025, the OECD area is poised for a partial recovery following its 1.5% demand decline in 2025. India, Southeast Asia, the Middle East and North Africa (MENA) region, and other developing economies continue to show relatively stronger growth prospects.

At the global level, excess capacity increased to 640 million metric tonnes (mmt) in 2025, exceeding total OECD steel production by more than 200 mmt, and is projected

to continue rising through 2028. Global steelmaking capacity has increased for four consecutive years, reaching a new high of 2445 mmt in 2025. A share of this is export-oriented. Regional developments have diverged significantly, however, with the OECD area contracting while non-OECD economies recording growth during this period. India and Southeast Asia have been significant drivers of the Asian capacity expansion, supported by relatively strong demand growth and, in the case of Southeast Asia, inward foreign direct investment. The Middle East, particularly Iran, is also a significant source of new capacity additions.

As steel demand contracts in China, steel producers there are diverting surplus production, at an unprecedented scale, to international markets to make up for lost domestic sales. China's annual exports have nearly doubled over the last three years, with its 131 mmt export volume last year surpassing the combined exports from the rest of Asia for the first time in recent history. Market-oriented producers in Europe, North America and Latin America have also suffered steel export declines in recent years, as China's exports surged.

China's steel subsidy rate has nearly doubled since 2019, a trend that will sustain excess capacity in the years ahead. Capacity swap programmes to replace BF-BOF with EAF and other low-emission technologies are not delivering the expected net capacity reductions, as new low-emission capacity is being added without equivalent retirement of existing capacity.

Source: OECD Steel Committee, 99th session, 23-24 March 2026, Paris

2025: A Year in Review for Green Steel

After several years of growing optimism, the global green steel and green iron sector is entering a pivotal moment. Momentum slowed in 2025, with new project announcements captured in the *green steel tracker* falling from a peak of 15 projects in 2021 to just two in 2025. Planned primary green steel production capacity for 2050 currently represents less than 2% of today's total global steel production.

Despite the slowdown in announcements, 2026 is set to be a decisive year for delivery. The tracker identifies Stegra's Boden project in Sweden as the most significant near-term milestone in 2026. It represents the first potential full-scale commercial commissioning of green steel. Several pilot and demonstration projects are also scheduled to advance this year, including in Germany and the United States.

Successful commissioning of Stegra in Boden in 2026 and the roll-out of the longer-term projects in the Hybrit alliance of SSAB, LKAB and Vattenfall, alongside pilot projects globally, will impact the sector in the coming years. These projects will

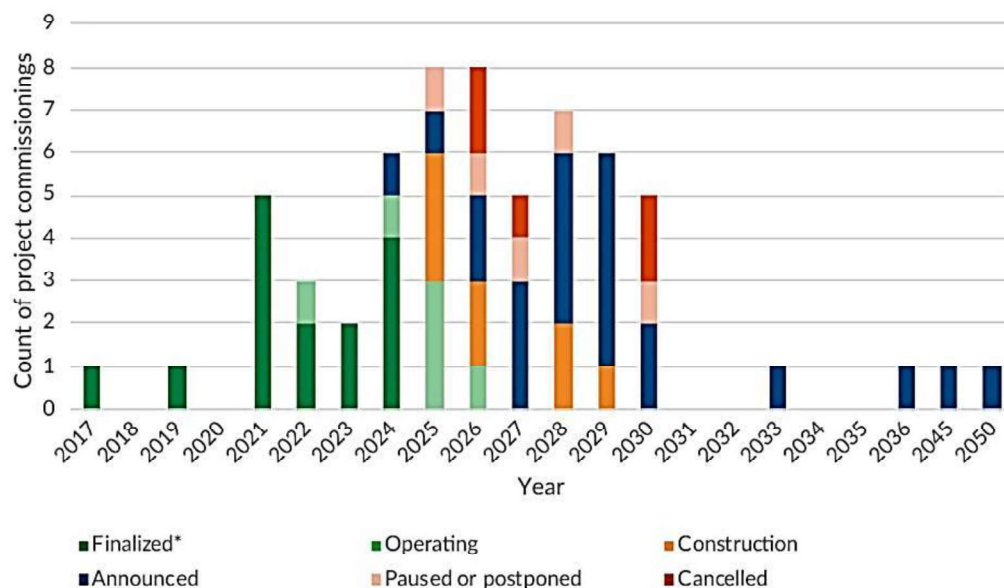
influence confidence and the pace of transition not just in Sweden and not just in steel production, but internationally and across industry in the coming years.

However, the *green steel tracker* shows that delays are common among projects with publicly reported commissioning dates, while limited transparency makes it difficult to assess timelines for many others. In 2025, several high-profile projects, particularly in Europe, were paused or cancelled.

Planned capacity gap

LeadIT's analysis of tracked projects shows that reaching net-zero by 2050 will take many more green steel projects than are planned. We calculate that less than 2% of what is needed is currently publicly announced. At the moment, planned primary green steel capacity by 2050 totals 28 million tonnes per year, alongside 18 million tonnes per year of green iron used as feedstock for steelmaking. These volumes represent only a small fraction of today's 1800 million tonnes per year of global steel production, including both primary and scrap-based output. This underscores the scale of ambition still required to decarbonize the sector.

Progress on the ground also remains limited. At present, only around 270 000 tonnes per year of green iron capacity and 60000 tonnes per year of green steel capacity are operational, meaning only a small share of announced projects has reached production.



*Research and development projects that are currently operational or have finished testing

Project status by planned commissioning year, global (source: [Green Steel Tracker](#))

The role of policy

Despite falling short of emissions reduction targets so far, incumbent global steelmakers continue to signal commitment to decarbonization, even as they face rising costs, weak demand, and uncertain policy environments. Future policy intervention may prove decisive in sustaining momentum until green steel becomes cost-competitive at scale.

Policy support to get first-of-a-kind green steel projects up and running can deliver benefits far beyond any single plant by accelerating learning, proving the technology at scale, and helping create early markets and confidence across the entire sector.

- The start of the EU Carbon Border Adjustment Mechanism's definitive phase from 1 January 2026 may begin to shape trade and decarbonization decisions, as importers must surrender CBAM certificates priced in line with the EU Emissions Trading System, with effective certificate obligations phased in as free allowances are withdrawn for EU producers.
- The announcement at COP30 in Belém that there will be increased collaboration between certification bodies to align on a global green steel standard or on compatibilities between standards. While still in its early days, this can be a major accelerator for the sector, as it simplifies the process of qualifying a product as being "green steel".

In summary, meaningful progress is contingent on large, ambitious projects surviving these difficult times, where a combination of declining global steel prices and weak market conditions for European Union steel producers has slowed momentum. Bringing back momentum and confidence could require policy interventions, with 2026 shaping up to be a pivotal year for the steel transition.

Source: The Leadership Group for Industry Transition ([LeadIT](#))

Financing Green H₂ Ironmaking in Emerging Economies

SEI's *Finance for Sustainable Development Program*, in collaboration with the Oxford Institute for Energy Studies, has analyzed the financial challenges of decarbonizing one of the most emissions-intensive industries: iron and steel production. The study outlines a blueprint for a hypothetical green hydrogen-based ironmaking project in a lower-income country, designed to produce low-carbon iron for export to higher-income markets.

The iron and steel industry accounts for 7-9% of global emissions, making it the second-highest emitting industrial sector after cement. A significant share of these

emissions stems from the ironmaking process, where coal and coke are traditionally used to reduce iron ore in blast furnaces. Substituting these fossil-based reductants with green hydrogen presents a viable pathway to decarbonization. Using hydrogen as a reducing agent not only eliminates direct CO₂ emissions but also aligns the sector with global climate goals.

Green hydrogen, produced via renewable electricity, is central to this proposed transition. The study envisions a model green hydrogen-based ironmaking project with an estimated capital cost of USD 9 billion. This ambitious facility would produce green hot briquetted iron (HBI) at a levelized cost of USD 690 per tonne. Although this cost represents a 100% premium over traditional “grey” HBI, it underscores the transformative potential of the project with the appropriate support mechanisms. In addition, with technological advancements, government and industry support, and accelerated adoption, these costs are expected to decrease in the medium to long term.

Key cost drivers include green hydrogen production, estimated at USD 4.84 per kilogram, and clean electricity, projected at USD 45.5 per megawatt-hour. These figures highlight the critical need for abundant, low-cost renewable energy to ensure the project’s viability.

Financing challenges and solutions

Financing a world-scale green hydrogen-based ironmaking plant poses formidable surmountable challenges. The study emphasizes that success depends on establishing a robust commercial structure anchored by long-term contracts. These contracts must address the “green premium” associated with low-carbon iron and ensure a consistent supply of specialized iron ore.

Carbon pricing under existing Emissions Trading Systems (ETS) is unlikely to provide sufficient support for such projects. However, targeted policy interventions, such as carbon contracts for difference (CfDs), can offer fixed price support over extended periods. These mechanisms can help de-risk investments by stabilizing revenue streams, making the project more attractive to capital providers.

Unlike traditional ironmaking plants, which are typically located near fossil fuel resources, green hydrogen-based facilities can be situated in regions with abundant and affordable renewable energy. This flexibility allows industry investors to prioritize areas with low-cost clean electricity, such as solar and wind-rich regions in some low- and lower-middle income countries (LLMICs).

The study also suggests the potential to decouple the iron and steel supply chain. Green ironmaking plants could be established in energy-efficient locations, while

steel production facilities remain closer to end markets, optimizing logistics and reducing overall costs.

For the global iron and steel industry to embrace green hydrogen technologies, supportive policy frameworks will be essential.

Key recommendations include:

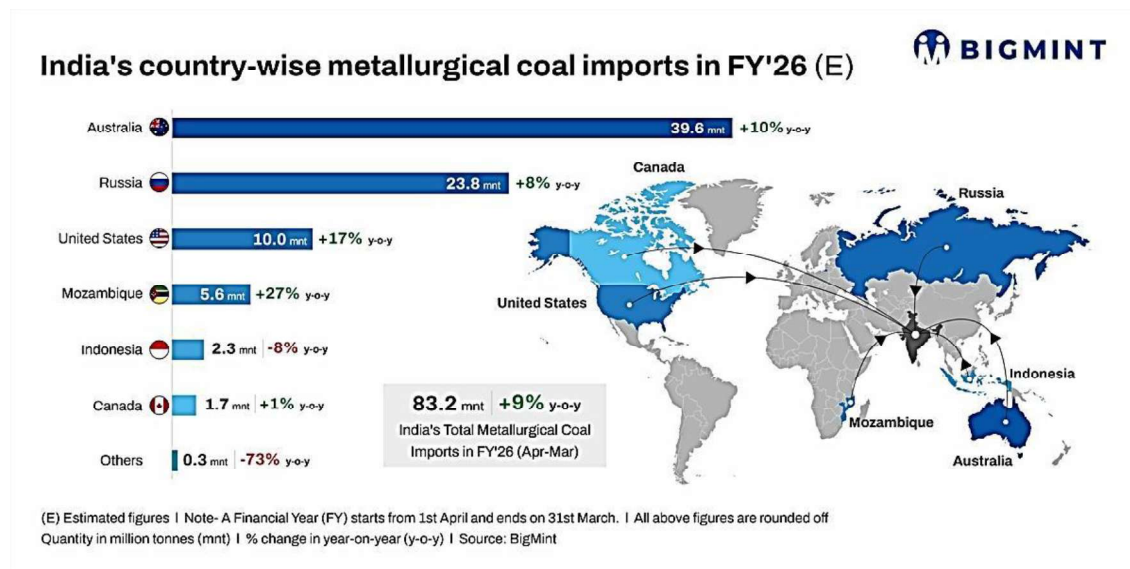
- Establishing long-term purchase agreements to secure market demand for green iron products.
- Developing infrastructure for renewable energy and hydrogen production in regions hosting these projects.
- Creating financial incentives and mechanisms to bridge the cost gap between green and grey iron production.

As the world shifts toward net-zero emissions, projects like this offer a promising roadmap for reducing emissions in hard-to-abate sectors. They also offer LLMICs an opportunity to become pivotal players in the low-carbon economy by leveraging their renewable energy resources.

By addressing the emissions-intensive ironmaking process head-on, this research paves the way toward a sustainable and decarbonized future in one of the world's most essential industries.

Source: SEI (Stockholm Environment Institute) 13 December 2024

India's Met Coal Imports Expected to rise 9% y-o-y in FY'26



India's imports of metallurgical coal (including coking coal and pulverised coal injection) are projected to rise 9% y-o-y to 83 million tonnes (mnt) in FY'26. Imports

of coking coal are expected to increase 11% y-o-y to 63 mnt, while pulverised coal injection (PCI) volumes are likely to rise 3% to 20 mnt.

The growth was primarily driven by higher steel output in India. Policy-led shifts - the quantitative restrictions on met coke imports - also boosted coking coal sourcing.

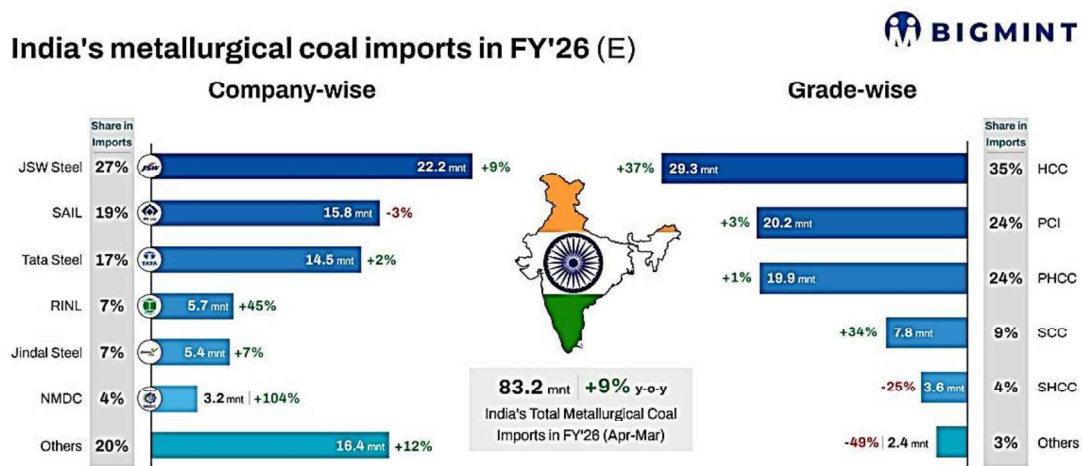
India's structural dependence on coking coal imports persists as high ash content in Indian coking coal limits its direct use in blast furnaces, requiring reliance on imported material for around 90% of demand. Only a small fraction of domestic coal is suitable for steelmaking after washing.

Higher steel production was the primary driver of India's rising metallurgical coal demand. India's crude steel output is projected to rise about 11% y-o-y to 168 mnt in FY'26, with hot metal production expected to increase 6% to 98 mnt.

Blast furnace-based production, which accounts for a significant share of India's steel output, is heavily dependent on coking coal. Increased hot metal production directly translates into higher coke consumption, thereby raising coking coal imports.

Parallely, demand from the foundry segment also contributed to increased coking coal consumption. Foundries use coke derived from coking coal in cupola furnaces for casting iron components used in automotive, infrastructure, and machinery sectors. Moderate growth in these downstream industries has led to steady demand for foundry-grade coke, indirectly supporting coking coal imports.

India's coking coal import mix shifted in FY'26, reflecting steel mills' efforts at cost optimisation and diversification of supply. Imports of hard coking coal (HCC) are estimated to have increased sharply by 37% y-o-y to 29 mnt, while premium hard coking coal (PHCC) volumes remained stable at nearly 20 mnt.



(E) Estimated figures | JSW steel includes Bhushan power | Tata Steel includes NINL | All above figures are rounded off
 Quantity in million tonnes (mnt) | % change in year-on-year (y-o-y) | Source: BigMint

Steelmakers are increasingly blending premium grades with lower-cost hard coking coal from multiple origins to optimise input costs without significantly affecting blast furnace performance.

In terms of region-wise sourcing, besides stronger inflows (+13%) from Australia, higher availability of low-volatile coking coal from the US supported increased imports from the region (+17%), aided by competitive pricing and flexible cargo options. Russian imports (+12%) also gained traction due to discounted pricing following trade dislocations. Supplies from Mozambique increased as well (+27%), supported by higher output from the Moatize basin and suitability of mid-volatile coal for blending.

At the same time, PCI usage increased modestly. PCI allows steelmakers to partially substitute coke in blast furnaces, reducing the coke rate and overall production costs. This was also driven by volatile coking coal prices, due to which Indian steel mills increased PCI usage as a cost-control measure.

Government policy also played a significant role in lifting coking coal demand. Quantitative restrictions on low-ash metallurgical coke from overseas reduced availability of imported coke, pushing steelmakers to increase in-house coke production and, by extension, coking coal imports.

The restrictions, initially imposed in December 2024 and later extended through 2025, capped imports at 2.85 mnt annually with quarterly allocations of 713,583 tonnes, as per government notifications. These measures were introduced following concerns from domestic producers over low-priced imports, particularly from Indonesia.

As a result, domestic metallurgical coke production rose 9% y-o-y to 47.56 mnt in 11MFY'26, indicating higher capacity utilisation.

However, in December 2025, India imposed a provisional anti-dumping duty ranging within \$60.87-130.6/t on imports from key supplying countries, including China, Indonesia, Colombia, Japan, and Russia. At the same time, quantitative restrictions were withdrawn, making imports freely permissible but subject to duties.

Outlook

India's blast furnace capacity expansion is expected to sustain demand growth for metallurgical coal in FY'26. Around 3 mnt of fresh capacity (across the environmental clearance and consent-to-establish stages) were approved in FY'25. Overall, coking coal demand is set to increase from 48 mnt in FY'24 to over 70 mnt by FY'30.

To accelerate domestic production, the government has classified coking coal as a "critical and strategic mineral" under the Mines and Minerals (Development and Regulation) Act, 1957. The move brings coking coal under the National Critical Mineral Mission, which will help streamline approvals, fast-track clearances, and accelerate development of deep-seated and technologically complex deposits.

However, due to domestic coking coal's high ash content and the resultant lack of suitability for steelmaking use (despite washing), it is unlikely that this policy intervention will significantly help India curtail imports.

India is also pursuing overseas asset acquisitions, particularly in Southeast Asia, to secure long-term supply outside of Australia. Delegations to countries such as Indonesia and Malaysia are planned to explore investment opportunities. Additionally, steelmakers are ramping up efforts to ensure raw material security: JSW Steel will develop the Minas de Revuboa coking coal mine in the Moatize coal basin, Mozambique, while NMDC is exploring the feasibility of reserves in Canada.

Similarly, as part of its latest trade deal with the US, India intends to purchase \$500 billion worth of American goods over the next five years, including energy products such as coking coal. This will further reduce India's heavy reliance on Australian coking coal, which accounts for over 50% of total imports.

However, in March and until the end of the Middle East conflict, supply-side constraints are expected. Elevated freight costs linked to geopolitical tensions may affect import economics and sourcing patterns, keeping purchases limited.

Source: BigMint Bureau, 26 Mar 2026

Challenges in Secondary Aluminium Production

The primary objective of the secondary aluminium industry, or its function when viewed in the context of the overall aluminium industry, is to introduce the maximum amount of aluminium material into the secondary cycle, to ensure that the secondary cycle progresses on a "closed-loop recycling" basis and to minimise metal loss and maximise energy efficiency in each cycle's scrap preparation, melting and refining stages. This is the ideal outcome.

But, every sustainable technological activity, including secondary metal production, also demands energy and generates carbon emissions. Recycling is not cost-free: we need energy.

Aluminium recycling: From scrap to metal

Aluminium is a “renewable” material. Aluminium products perform their functions throughout their lifespan. The end of their lifespan means the loss of properties such as high strength, corrosion resistance, high elasticity and electrical and thermal conductivity.

However, scrap aluminium, when reprocessed under appropriate conditions, re-enters the system as secondary aluminium, regaining all these lost properties. Approximately 0.9-0.95 tonnes of new aluminium material can be produced from 1 tonne of scrap aluminium by recycling it (due to scrap preparation and melting losses).

The aluminium economy is circular. Aluminium products are only used; they are not wasted. When their lifespan ends, they are reintroduced into the system as raw materials for the secondary aluminium industry, provided they are processed under appropriate conditions. Therefore, every gram of aluminium that is not recycled is a “loss” and allowing this is a “mistake.”

The aluminium recycling process is ultimately a remelting process. This means that it is not possible to reduce aluminium oxide (Al_2O_3), the raw material for the production of primary metallic aluminium, back to metal and the possibility of removing the physical and chemical impurities and contaminants contained in the melt is limited, while achieving the chemical composition of the target alloy and the desired metallurgical properties is necessary. Therefore, wrought alloys can be recycled back into casting alloys (downcycling) and primary metal or new scrap is added to dilute the impurities to acceptable levels.

Oxides come through the scrap; the amount of oxide increases with the surface area of the scrap and is therefore inversely proportional to the scrap particle size, or oxides are formed during the remelting process through reaction with air or through the reduction of impurities.

Table 1: Global average emissions from aluminium production,

Process	Present Global Average Emissions ($\text{tCO}_2/\text{t Al}$)	Present BAT Emissions ($\text{t CO}_2/\text{t Al}$)	Future BAT Emissions with CCS ($\text{t CO}_2/\text{t Al}$)	Future Emissions with inert anodes ($\text{t CO}_2/\text{t Al}$)
Primary Production				
Alumina refining	2.6	1.0	0.2	0.2
Anode production	1.0	0.813	0.5	~0.01
Electrolysis	2.0	1.4	0.25	0
Total	~5.6	~3.2	~1.0	~0.2
Recycling				
	0.5- 0.6			

Table 1 presents the data for the global average emissions from aluminium production, including present and future Best Available Technologies (BAT) for raw materials production and smelting (based on using power from renewable resources).

The fundamental driver of the aluminium recycling industry is the preservation of the enormous electrical energy embedded in the metallic bond of refined aluminium. In primary production, the extraction of aluminium from alumina (electrolysis) requires overcoming an extremely high enthalpy of formation.

This process involves the electrolytic reduction of alumina in a molten cryolite bath, a method that has remained fundamentally unchanged for over a century despite incremental efficiency improvements. Because primary smelting is so energy-intensive, the resulting metallic aluminium acts as an “energy bank.”

Recycling allows for the withdrawal of this energy with minimal additional input, as the process merely requires the thermal energy to reach the melting point, rather than the chemical energy to break the Al-O bond.

The hidden complexity of secondary aluminium production

The global metallurgical sector increasingly recognises that while aluminium is theoretically infinitely recyclable, the practical execution of a closed-loop system is an exceedingly difficult industrial endeavour.

The narrative of aluminium as a “green” metal rests upon a stark thermodynamic contrast: the primary production of aluminium from bauxite ore via the Hall-Héroult electrolytic process is one of the most energy-intensive industrial activities on the planet, requiring approximately 12,500 to 16,000 kWh of electricity per tonne of metal produced.

In contrast, the secondary synthesis of aluminium from scrap requires only 5% to 10% of that energy, representing a 90-95% monumental reduction in the total energetic footprint.

However, this energy saving serves as a theoretical ceiling that is frequently lowered by the extreme technical and systemic challenges inherent in the recycling value chain. The industry’s current struggle is defined by a chaotic landscape of mixed metal, painted profiles, oily machining chips and contaminated automotive parts that complicate the path toward true circularity.

The secondary aluminium production process is more complex and unique than the primary aluminium production process. It is one of the industries that requires the most “tacit knowledge” among metallurgical processes. The increasing use of aluminium and its alloys also means a diversification of secondary aluminium

sources. In this context, secondary aluminium production is not a standard process. Different scraps yield different efficiency and quality results in different melting systems. The ability to analyse and find solutions for each case is required. At the same time, close collaboration and interaction with other engineering disciplines are necessary for an efficient production process.

Different types of post-consumer scraps:

- *Aluminium metal and alloys are a material that finds use in almost all sectors and industries. Naturally, each application brings different properties, and therefore, it is possible to encounter aluminium materials with very different alloys and physical structures. Therefore, a great deal of variety and diversity in aluminium scrap enters the system as raw material for the secondary industry, and this diversity and difference lead to increased complexity in the “scrap preparation,” “melting” and “metal refining” processes. For example, the use of multi-material applications in industries like packaging and the automotive industry, which are among the most important sources of scrap, presents itself as an engineering paradox.*
- *Since the main raw material for secondary plants is “urban mines,” they are established in locations close to city centres. Therefore, the technology of the plant itself must also be environmentally friendly.*
- *One of the primary reasons why aluminium recycling is not an easy task is the fragmented nature of the recycling chain. Unlike primary production, which is often vertically integrated from the mine to the smelter, the recycling process involves a series of independent actors: collection centres, scrap yards, shredder operators and secondary smelters. Each of these actors optimises their own portion of the process, often to the detriment of the overall system. Collection centres focus on volume; scrap yards focus on rapid throughput and secondary smelters are left to manage a feedstock that is frequently contaminated with multiple alloys, coatings, moisture and non-metallic residues.*

This fragmentation leads to a “difficult input” scenario where scrap enters the furnace as a chaotic mixture rather than a refined raw material. Historically, the industry relied on simple sorting techniques such as magnetic separation to remove ferrous materials and eddy current systems to separate non-ferrous metals from trash. While effective at a basic level, these methods fail to distinguish between the hundreds of different aluminium alloy families. When various alloys, such as 6000-series extrusions and 3000-series beverage cans, are mixed before melting, the resulting melt becomes an unpredictable metallurgical soup.

- *The most profound technical challenge in aluminium recycling is the irreversible accumulation of deleterious impurities, often referred to as “tramp elements.” Unlike*

steel or copper, where certain impurities can be oxidised or slagged off during the melt, aluminium is a highly reactive metal that acts as a solvent for a wide range of foreign elements. Once an impurity like iron or silicon enters the aluminium melt, removing it is metallurgically impractical or prohibitively expensive.

Because impurities cannot be easily removed, the industry currently manages this chemical complexity through two primary strategies: downgrading and dilution. Downgrading involves using high-purity scrap to produce lower-grade alloys, such as using extrusion scrap to make engine blocks. Dilution involves adding a “sweetener” or primary aluminium to the melt to lower the concentration of impurities below critical levels (in the case of wrought alloys, scrap to wrought alloys semi-product). While these strategies allow for the reuse of metal, they are inherently unsustainable in a truly circular economy. Continuous downgrading eventually leads to a surplus of scrap that is too contaminated for any use, while dilution perpetually requires the input of new, energy-intensive primary metal.

- The melting process itself is a major source of metal loss. When scrap containing paint, plastic, or machining oil is charged directly into a furnace, these contaminants burn off, creating an oxidative environment. This leads to the formation of dross, a mixture of aluminium oxide and metallic aluminium that floats on the surface of the melt.*
- To minimise oxidation and dross formation, advanced recyclers employ decoating or delacquering systems. These systems thermally remove organic contaminants in a controlled, low-oxygen atmosphere at temperatures around 300-550 °C. By removing the “dirty” elements and VOC content before the metal enters the melt, these systems preserve the alloy properties and ensure higher recovery yields.*
- When dross is formed, it must be processed to recover as much metallic aluminium as possible. This is traditionally done in a Rotary Salt Furnace (RSF), where salt fluxes (NaCl and KCl) are added to the dross to promote the separation of metal from oxide. The residue of this process is known as salt cake or salt slag, a hazardous waste containing metallic aluminium, aluminium oxide and concentrated salts.*

Salt cake represents a significant environmental challenge. It is highly leachable; if disposed of in standard landfills, the salts can contaminate groundwater. Furthermore, the reactive metallic aluminium in salt cake can react with moisture to produce explosive hydrogen gas or toxic ammonia gas. Because of these risks, the disposal of salt cake is becoming increasingly regulated and costly, creating an economic incentive for salt-free dross treatment or salt cake utilisation technologies.

The transition to a more efficient recycling model depends on several factors:

Technological Integration

- Combining AI-driven optical sorting with high-precision **Laser-Induced Breakdown Spectroscopy** (LIBS) and X-ray telescope (XRT) sensors to produce high-purity alloy streams.
- AI-supported furnace monitoring to manage metal and energy efficiency
- Online molten metal analysis to avoid downcycling

Scrap Preparation

Implementing universal decoating and thermal pre-treatment to reduce oxidation and metal loss.

Metallurgical Innovation

- Developing recycle-friendly alloys that can function at high impurity levels, reducing the dependency on primary aluminium for dilution.
- Developing new melting technologies by considering scrap specifications.

Policy and Design

- Enforcing Design for Recyclability guidelines and extended producer responsibility (EPR) schemes to ensure that products are designed with their end-of-life in mind.
- Raising public awareness about scrap metal collection and sorting at the source.

Conclusions

The assertion that aluminium recycling is “not an easy job” is supported by the immense complexity found at every stage of the process. From the thermodynamic inefficiencies of remelting to the metallurgical crisis of iron and silicon accumulation, the path to circularity is blocked by significant technical hurdles. The industry must navigate the hazardous management of salt cake, the respiratory risks of smelting emissions, and the economic volatility of global scrap markets.

By addressing these challenges through a holistic, systems-thinking approach, the aluminium industry can move beyond simple downgrading and dilution toward a high-value, sustainable circular economy. The energy savings of remain the ultimate prize, but achieving them consistently requires a relentless focus on process discipline and technological innovation.

However, it should be remembered that sustainability is not a journey that will last forever; it is merely a matter of postponing the expected end.

{Laser-Induced Breakdown Spectroscopy (LIBS) is a rapid, non-destructive, atomic emission technique that uses a high-energy, pulsed laser to vaporize a tiny amount of a sample, forming a light-emitting plasma. A spectrometer analyses this light, acting as a "fingerprint" to identify elemental

composition—including light elements like —in solids, liquids, or gases within seconds, often with no sample preparation.}

Source: AL CIRCLE 18 March 2026

Heavy Industry Low-Carbon Transition Cooperative Research Centre

Heavy Industry Low-carbon Transition Cooperative Research Centre (HILT CRC) is a collaborative venture that brings together industries, researchers, and government organisations to share the responsibility for the big shift of decarbonisation. It has the scale to make a difference and seek new low-carbon technologies and methods that will overcome barriers, and help transition the steel, iron, alumina and cement industries to decarbonise heavy industry. It aims to de-risk decarbonisation pathways for heavy industries.

Strategic Goals

All HILT CRC projects are conceived, developed and implemented with industry partners from an industry perspective, and underpinned by our impact-driven strategic goals.

Research Projects

HILT CRC's projects span three research programs: Processing Technologies, Cross-Cutting Technologies, and Facilitation Transformation. HILT CRC's research aims to accelerate the development of decarbonisation technologies that can be commercialised and lead to net-zero production.

Research Strategy & FOCUS

HILT CRC's research strategy was developed in close consultation with their partners across the heavy industrial sector in Australia and overseas. The strategy identifies outputs, pathways and focus areas that drive the development of projects and contribute to the planning for infrastructure.

Pathways to Decarbonise Heavy Industry

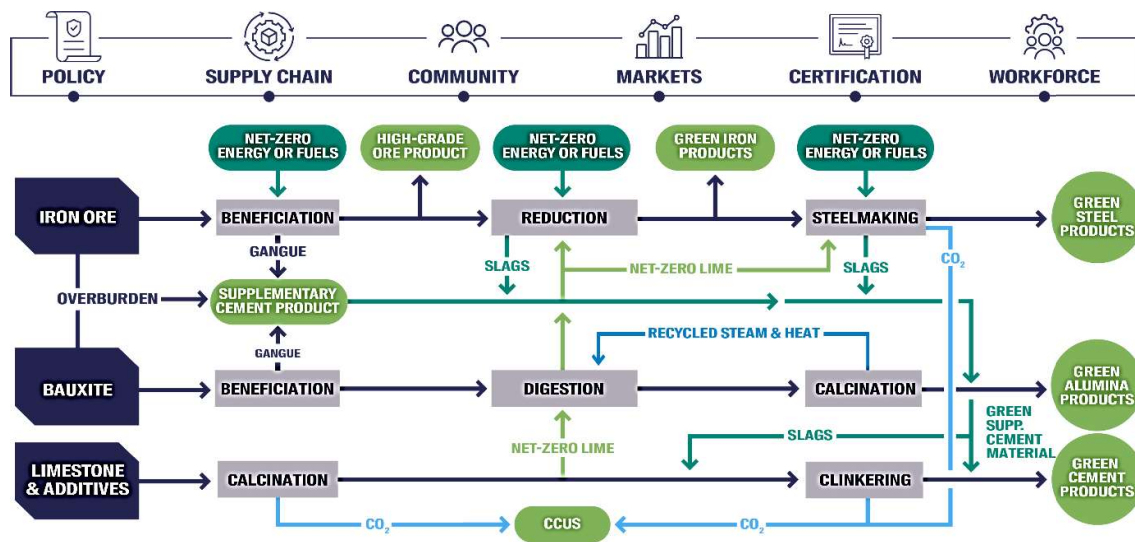
HILT CRC has mapped decarbonisation pathways and areas where technology can be deployed and have a significant impact on decarbonisation.

Research focus areas fall into five focus areas:

- Beneficiation to improve ores and make them more suitable for decarbonised processes.
- Reactor technology needed to progress decarbonised processes.

- Energy technology – recognising the criticality of supply and integration of low-carbon energy and fuels for heavy industry decarbonisation.
- Circularity, including carbon capture, utilisation and storage (CCUS).
- Facilitating transformation to address the non-technical barriers to decarbonisation.

Established in 2021 and operating as a registered organisation in Australia, HILT CRC brings together heavy industry companies, research institutes and the Australian Government in order to move projects from laboratory research to pilot-scale implementation.



Green Metals Innovation Network

In 2025, Heavy Industry Low-carbon Transition Cooperative Research Centre (HILT CRC) and the Commonwealth Scientific and Industrial Research Organisation announced the creation of the *Green Metals Innovation Network* - An initiative aimed at accelerating the development of low-emission metal production. The Green Metals Innovation Network (GMIN) aims to connect researchers and industry to advance the development of green metal production in Australia.

Green Metals Innovation Network is leading a \$10 million project funded by the Australian Federal government to advance collaboration between research and industry partners to support the development of a green metals industry in Australia.

The Green Metals Innovation Network (GMIN) will bring together research, government and industry in a "Team Australia" approach to address key technical and economic challenges for green metals in the iron, steel, alumina and aluminium sectors.

As global economies transition towards a more sustainable future, demand is growing for key materials such as metals to be produced in a more environmentally friendly manner.

Fostering new green metals pathways

Over four years, GMIN is partnering with the Heavy Industry Low-carbon Transition Cooperative Research Centre (HILT CRC) to lead the GMIN project. Together they are engaged with industry and research to advance the development of a green metals industry by:

- Promoting faster adoption of green metals processing
- De-risking the development and deployment of new technologies suited to Australian ores and conditions
- Driving understanding of how to lower costs and increase performance in new processing pathways
- Identifying STEM education opportunities to train and support a skilled green metals workforce.

GMIN will co-invest in research projects, research facilities, talent development, knowledge sharing and insights and foresighting to help drive Australia's green metals industry forward, strategically positioning the resources sector as a leader in global supply chains for value-added sustainable green metals and materials.

Source: AL CIRCLE, 26 March 2026

Decarbonisation Pathway of the Aluminium Industry – Crucial Synergy of Technology, Recycling, and Renewable

The importance of aluminium for the global energy transition is undeniable, yet the fact remains that its production is one of the most carbon-intensive processes in the industrial sector. According to the International Aluminium Institute (2023), the aluminium value chain accounts for roughly *3 per cent of global direct industrial carbon emissions*. Primary aluminium production, which involves three key stages, is the main contributor to this footprint. On average, each tonne of primary aluminium emits about 14.8 tonnes of carbon dioxide equivalent (CO₂e). When the emissions profile is broken down across the production chain, bauxite mining contributes

around 0.1 tonnes of CO₂e per tonne of aluminium, alumina refining adds approximately 2.6 tonnes, and the primary smelting process accounts for 14-15 tonnes of CO₂e. This stark carbon intensity presents a structural challenge for an industry that is simultaneously positioned as a cornerstone of a low-carbon economy.

As a result, the sector is increasingly focused on deep decarbonisation pathways, with industry-wide targets aiming to reduce emissions intensity to around 11.5 tonnes of CO₂e per tonne of aluminium by 2030 and ultimately to as low as 0.5 tonnes by 2050. The key question is how these ambitious reduction targets can realistically be achieved while meeting the rapidly rising global demand for aluminium.

Advanced technologies: Inert anode and carbon capture & storage

While the world is wondering how to achieve decarbonisation in the aluminium industry, technologies like Inert Anode and Carbon Capture & Storage are quietly playing their key roles. Inert anode technology is a breakthrough process that replaces traditional consumable carbon anodes with non-consumable, inert materials. It releases oxygen as a byproduct instead of CO₂, eliminating direct greenhouse gas emissions from the smelting process.

RUSAL, Russia's largest producer of primary aluminium and one of the world's largest aluminium producers, recently, has commissioned the first industrial electrolyser using inert anodes. The company that has been decarbonising its aluminium production by integrating renewable energy and recycled metal has made another step of progress by embracing inert anode technology. The new unit is designed to replace the most widely used smelting technology in Russia, demonstrating a practical pathway to decarbonise existing production infrastructure. With this launch, RUSAL becomes the first company globally to move inert anode technology from industrial trials into commercial implementation.

For every tonne of aluminium produced using this technology, approximately 900 kilograms of oxygen are released into the atmosphere, eliminating direct greenhouse gas emissions from the smelting process itself.

For RUSAL, the technology has already moved beyond pilot stage. Since 2017, RUSAL has systematically advanced inert anode electrolysis, producing approximately 6,000 tonnes of commercial-grade aluminium and demonstrating consistent process stability and product quality. RUSAL's low-carbon brand ALLOW INERTA - aluminium produced with inert anode technology - has already been supplied to customers across multiple industries.

With global policies in place aimed at tightening requirements on embedded carbon emissions, access to such materials becomes critical. Aluminium made with inert anode technology enables RUSAL to help customers meet the most stringent regulatory standards and position their own products as leaders in the low-carbon transition.

Like RUSAL, Alcoa and Rio Tinto through their joint venture have also brought forth their widely cited inert anode initiative, which is already in operation since late 2025. In November, Alcoa and Rio Tinto together launched the 450 kA commercial-size inert anode cell at Rio Tinto smelter in Alma (Québec). However, the exact volume of the metal being produced and shipped from this new cell has not been disclosed.

Iceland-based Arctus Aluminium in collaboration with local industrial partners like Nordural is also actively developing its own inert anode smelting approach focused on *Vertical Electrode Cell (VEC)* technology with vertical inert anodes and low-temperature electrolyte operation. Germany's TRIMET Aluminium is also one of them involved in inert anode development in collaboration with Icelandic partners, aiming to commercialise in Europe by around 2030

Among the advanced technologies, carbon capture has become another crucial system in the decarbonisation of aluminium production. RUSAL has brought Russia's first industrial carbon capture, utilisation, and storage (CCUS) project, which captures CO₂ using a closed-loop water circulation system to prevent its release into the atmosphere. Over the next decade, this initiative is expected to eliminate 1.8 million tonnes of CO₂ equivalent emissions. This achievement is a key element of RUSAL's broader strategy to reduce its carbon footprint and implement climate-resilient technologies.

Other technologies available in the market are HalZero, a proprietary technology from Hydro, a leading aluminium and renewable energy company, uses a closed loop recycling system for carbon and chlorine to eliminate CO₂ emissions from smelting. Then there's Mechanical Vapour Recompression, which employs electricity to boost the pressure and temperature of waste steam, offering a highly efficient alternative to fossil fuel boilers in refining.

Not to forget, there are advanced recycling technologies and innovation in sorting and removing impurities for higher volume of recycled aluminium.

Recycling and the role of recycled aluminium

Recycling and incorporating recycled aluminium is a proven solution to significantly reduce carbon emissions, as it consumes 3 to 5 per cent of the energy needed for

primary metal production. Furthermore, about 80 to 95 per cent of greenhouse gas emissions can be reduced at aluminium recycling compared to primary metal production. This means, instead of 15 tonnes of CO_{2e} generated from one million tonne of primary aluminium, only 0.52 tonnes of CO_{2e} are emitted per tonne of recycled aluminium.

Owing to the 75 per cent post-consumer scrap content, Hydro's recycled aluminium boasts a carbon footprint as low as *1.9 kg CO_{2e} per kg of aluminium*. Also, with some variants containing up to 100 per cent recycled aluminium, have a carbon footprint below *0.5 kg CO_{2e} per kg of aluminium*. Alcoa's recycled aluminium contains at least 50 per cent of recycled content, while ALBA's, available in four variants, come with 15 per cent, 20 per cent, 30 per cent, and 50 per cent, recycled aluminium content, respectively. ALBA also offers recycled aluminium that generates net-zero to up to 4 tonnes of CO_{2e} per tonne of aluminium. Capral's recycled aluminium generates less than 8 kg and 4 kg CO_{2e} per kg of aluminium, respectively, made from a mix of post-consumer scrap and low-carbon primary aluminium.

These companies' initiatives towards producing recycled aluminium do not end here. Novelis has pledged to incorporate 75 per cent of recycled content in its products by 2030 and has launched the "3x30" vision to advance circular solutions, while Alcoa is developing the ASTRAEA process to purify post-consumer scrap, allowing lower-grade scrap to be used in high-end applications.

While global aluminium majors have advanced their recycled aluminium capabilities, RUSAL has taken a distinct technological lead in this space. The company has developed an electrolysis-based process to produce high-quality aluminium directly from scrap, including off-grade materials with higher impurity levels. This approach enables the conversion of lower-quality scrap into metal of P1020 grade, in addition to achieving low carbon footprint as this technology boasts high energy efficiency with about *9 MWh of energy* consumed to produce one tonne of aluminium from scrap.

Recycled aluminium mixed with primary aluminium produced from renewable energy is another practice towards decarbonisation, followed by EGA. The company offers aluminium containing both recycled metal as well as primary produced from renewable energy.

Renewable energy in decarbonisation

Talking about the usage of renewable energy in producing aluminium, RUSAL carries out 90 to 98 per cent of aluminium production with the use of renewable power. RUSAL's low-carbon aluminium brand ALLOW offers the metal produced using hydropower energy, *with a footprint below 4 tonnes of CO_{2e}* (Scope 1 and 2).

Primary aluminium industry can reduce carbon footprint by 60 to 75.5 per cent with the usage of renewable energy as a source of power, albeit subject to baseline energy mix and specific production technologies used. Electricity consumption is the single largest contributor to aluminium's carbon footprint, accounting for approximately 70 per cent of total emissions globally. Coal-fired aluminium production typically generates round 12.7 to 20 tonnes of CO₂e per tonne of aluminium. In contrast, with the use of renewable energy, such as hydropower or wind, carbon footprint remains between 4 and 5 tonnes of CO₂e per tonne of aluminium.

Even in the United States and Europe, aluminium is produced predominantly with the use of hydropower, which is why the industry in those countries has carbon footprint of about five tonnes of CO₂ per tonne. Aluminium produced by Century Aluminum uses 100 per cent renewable energy, sources being hydro and geothermal, *generating below 4 tonnes of CO₂ per tonne of aluminium.*

There are companies that are even exploring beyond local green grids by planning to set up production complexes powered by renewable energy. For instance, AM Green in India has entered into an agreement with Mitsui & Co. to explore investment options for constructing a green aluminium complex with capacity 1 million tonnes per year. The complex will have an aluminium smelter and alumina refinery powered by renewable wind and solar backed up by pumped hydro storage. This could be the first fully-integrated renewable energy aluminium plants globally. Rio Tinto in partnership with AMG Metals and Materials and NALCO are also planning to build integrated aluminium capacity. NALCO is actively installing captive wind and solar capacity to cut emissions at facilities.

Given rapidly growing electrical sector, RUSAL has particularly developed innovative, high-performance aluminium-scandium wire rod that offers higher strength and durability than other aluminium alloys, without compromising electrical conductivity. This product brings the discussion full circle that aluminium is central to energy transition while its production demands decarbonisation. This product of RUSAL reflects that dual reality – engineered for electrical infrastructure and produced using more than 99 per cent renewable energy.

The market fundamentals support this direction. In 2024, the global electrical sector drove strong aluminium demand, accounting for 16.3 *per cent of total consumption*. This trend is driven by large-scale investments in energy infrastructure and clean energy, with global investments exceeding USD 2 trillion.

Overall, while the aluminium industry faces significant challenges in reducing its carbon footprint, the combination of recycling, renewable energy, and technological

advancements such as inert anode and carbon capture presents a promising path toward achieving the sector's decarbonisation goals.

Source: AL CIRCLE, 26 March 2026

Turning Bauxite Residue into Refractory Bricks

What was once treated as a stubborn by-product of mining may now find a second life in industry. Researchers at the CSIR-Institute of Minerals and Materials Technology have worked out a way to convert leftover bauxite residue into refractory bricks capable of withstanding very high temperatures.

Residue from the bauxite extraction has, over time, added to the dust pollution and significantly altered the chemistry of nearby water bodies, thus making them more acidic. However, managing this residual material is a significant concern, especially in areas where mining activity is concentrated.

The CSIR-IMMT Bhubaneswar scientists have explored its potential as a raw material instead of treating it just as a residual waste. It is a heat-resistant product perfectly suited for heavy industrial use, including applications where materials can withstand extreme temperature conditions. The process reduces heavy reliance on freshly sourced inputs, while also addressing disposal challenges.

The bricks developed by using bauxite industry waste can resist temperatures up to 1,400 degrees Celsius. This can offer many industrial applications.

The development is now moving beyond the research stage. To facilitate practical use, the institute has entered into a technology transfer arrangement with Utkal Vanguard Engineering & Construction Pvt. Ltd. The agreement is expected to support scaled production and adoption in industrial settings.

The backdrop to this work is significant. Mining operations worldwide generate enormous volumes of residual material each year, making it one of the largest waste streams globally. In India, high levels of residual products are being produced in states such as Odisha, Jharkhand, Chhattisgarh, and Goa due to their mineral-rich landscapes.

This work at CSIR-IMMT, rather than focusing solely on containment and disposal, points to a more practical alternative, turning an environmental burden into a usable industrial resource.

Source: AL CIRCLE Article, 19 March 2026

Make Less, Make Better, Make New

Heavy industry sits at the core of the global economy and at the center of the net-zero challenge. Cement, steel, and chemicals are essential to modern life, yet together they account for a significant share of global emissions.

A clear framework has emerged for the innovations needed to reach net zero: **Make Less, Make Better, and Make New.**

Make Less focuses on reducing demand for virgin materials through smarter resource use. Lower-emission steelmaking is achieved by cutting material use while maintaining performance. Steel recycling and material efficiency solutions reduce waste and ease pressure on supply chains.

Make Better targets emissions reductions in today's industrial processes. Startups are improving efficiency and cutting emissions in steelmaking through electrified furnaces, novel process controls, and cleaner feedstocks.

Make New represents the most transformative leap: entirely new production pathways designed for low or zero emissions from the start. Startups are pioneering hydrogen-based ironmaking that eliminate fossil fuels altogether — opening the door to fundamentally cleaner industrial systems.

Red Mud: Environmental Liability or Strategic Resource

As global alumina refining accelerates, from expansion and new addition projects in India, China, Indonesia, the Middle East and a few other regions, a parallel curve is quietly steepening: the rise of red mud.

Also known as bauxite residue, red mud is the unavoidable by-product of the Bayer process used to refine bauxite into alumina. Red mud generation is estimated as 1.25 tonne generated for 1 tonne of alumina produced.

The challenge is no longer local. It is structural.

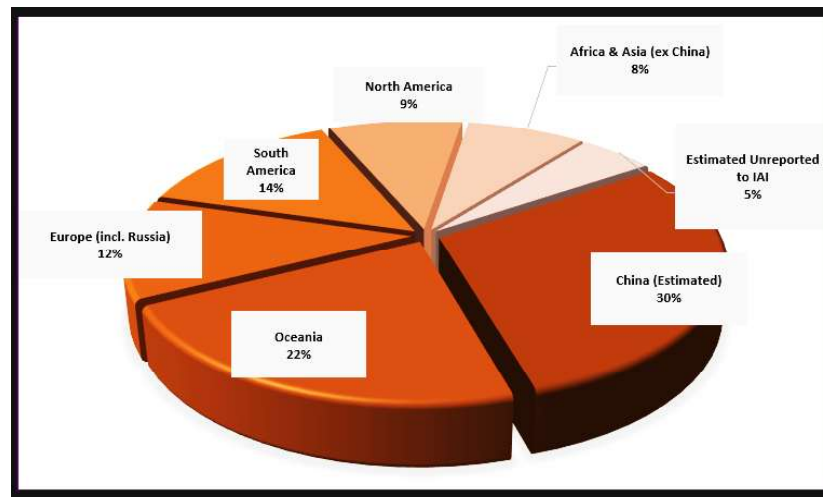
The scale of the problem

Red mud contains iron oxides (giving it its red colour), along with alumina, silica, titania, and residual caustic soda. Its high pH and fine particle size make storage complex and environmentally sensitive. Historically, residue has been stored in large impoundments or dry stacks, solutions that manage risk but do not eliminate it.

As refining capacity expands to meet growing aluminium demand from energy transition sectors, EVs, renewables, and infrastructure, the red mud question

becomes strategic. The industry is at a tipping point: continue to store, or start to valorise.

Forward-looking economies are choosing the latter.



Red mud generation by region (1974-2023)

From waste to resource: A shift in mindset

Red mud is not just waste. It is a secondary resource waiting for a viable business model.

Globally, three utilisation pathways are gaining traction:

Cement and construction materials

Red mud's iron and alumina content make it a candidate for clinker production and supplementary cementitious materials. Pilot projects in China and India have demonstrated partial substitution in cement and bricks. Scale, however, will depend on logistics integration. Refineries must co-locate or partner with cement plants to reduce transport cost, a key barrier to commercial viability.

Metal recovery (Iron, Rare Earths, Scandium)

With iron content ranging between 30-60%, red mud can serve as a low-grade iron ore substitute. More strategically, it contains trace rare earth elements and scandium, critical for aerospace alloys and clean energy technologies.

Countries like Australia are investing in extraction technologies to unlock scandium from residue streams. If commercially scaled, red mud could become part of the critical minerals value chain.

Economics can improve when recovery is integrated at the refinery stage rather than treated as a downstream waste-mining activity.

Carbon capture and environmental applications

Emerging research shows red mud can absorb CO₂ through mineral carbonation, reducing alkalinity while sequestering carbon. It can also be processed into materials for wastewater treatment and soil remediation.

Linking residue utilisation with decarbonisation credits could unlock new financing models under ESG frameworks.

What must change?

To move from pilots to mainstream, three intelligent interventions are required:

Policy signal

Mandate minimum utilisation targets for bauxite residue, similar to recycled content mandates in metals. Policy certainty drives investment.

Innovation clusters

Create industrial ecosystems where refineries, cement producers, steel plants, and research institutions collaborate. Red mud valorisation is a systems challenge, not a single-company solution.

Economic reframing

Shift accounting treatment, from “waste management cost” to “strategic secondary resource inventory.” This mindset changes capital allocation decisions.

The future: Liability or leverage?

The aluminium industry positions itself as a cornerstone of the energy transition. Yet its upstream footprint must align with that narrative.

Red mud is the industry’s credibility test.

If treated passively, it will remain a growing environmental burden. If treated strategically, it can become a source of critical minerals, construction inputs, and carbon solutions.

The question is not whether red mud will grow, it will. The real question is whether the industry grows its imagination alongside it.

Source: AL CIRCLE BLOG, February 24, 2026

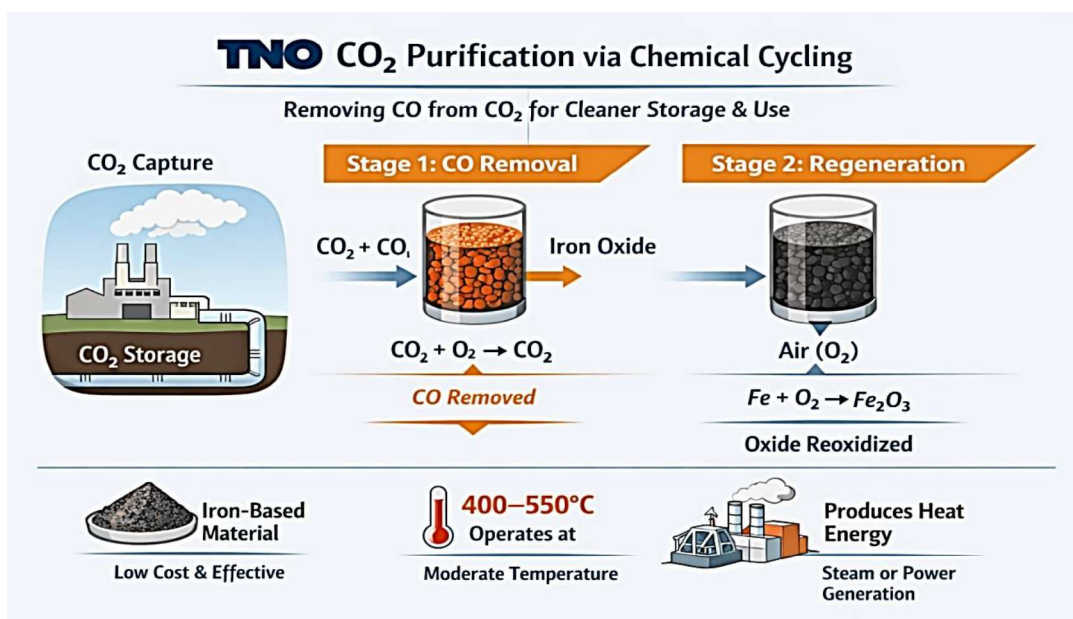
Technology for the Deep Purification of CO₂ from CO

The Netherlands Organisation for Applied Scientific Research (TNO) developed a method to purify carbon dioxide (CO₂) for underground storage or industrial use. The method removes carbon monoxide (CO) from CO₂ using a process called chemical cycling.

In carbon capture and storage, captured CO₂ often contains impurities. These impurities can damage pipelines, storage sites, or catalysts used in later processes. Carbon monoxide is particularly restricted, and its concentration must generally remain below 100 to 300 ppm. Existing purification methods often require high energy, complex equipment, or may introduce additional contaminants.

The proposed method uses metal oxide particles as oxygen carriers in a two-stage process. In the first stage, a gas mixture of CO₂ and CO passes through the metal oxide. The oxide releases oxygen, which reacts with CO and converts it into CO₂. During this reaction, the metal oxide will be reduced partially.

In the second stage, the reduced oxide reacts with air and becomes oxidised again, restoring it for reuse in another cycle. This process removes CO without adding other substances to the gas stream.



The researchers used thermodynamic analysis to select suitable materials. They evaluated oxides of nickel, copper, manganese, and iron under temperatures below 700°C and low CO concentrations. Copper and iron oxides excelled, while nickel and manganese were less stable. Both reaction stages released heat, indicating that the process could also produce usable energy for steam or electricity generation.

Iron-based materials were studied in more detail because it is widely available, non-toxic, and cost-effective. Several iron oxide materials supported by aluminium oxide were tested. The most effective sample, produced by an infusion method, operated for about 200 cycles at 400 to 550°C while converting CO to CO₂. The system also functioned effectively at CO concentrations of 2,000 to 4,000 ppm, which are typical of industrial gas streams.

Experiments showed that raising the temperature to around 450°C increased the time required for complete CO conversion, and further increases provided only limited improvement. As a result, the optimal operating temperature depends on the process design and how the released heat is used.

Although iron-based materials performed well, other materials may offer faster reactions or greater durability. Future work will test additional materials and evaluate the technical and economic feasibility of the process compared with methods such as cryogenic separation (energy-intensive) or catalytic oxidation (chemical process using a catalyst for oxidation).

Source: AL CIRCLE 10 March 2026

Entropy and Recycling: From Disorder to Meaningful Disorder

Metals and metallic alloys, thanks to their properties and functions, are critical to nearly every technology and industry. However, metal resources are non-renewable and undergo some mass loss during their use.

In general terms, process metallurgy underlies the extraction, refining and *recycling* of metals and is based on knowledge of transport phenomena, thermodynamics and reaction kinetics and their interactions in high-temperature heterogeneous metallurgical processes.

Aluminium, with its many superior properties, offers significant potential for improvement in process metallurgy, both through sustainable material design and its recyclability.

The often neglected concept of entropy is a key concept for both primary and secondary aluminium metallurgy.

Entropy

The word entropy comes from the ancient Greek word “entropē”, meaning “return”. Understanding the role of entropy in process metallurgy is challenging because the concept of entropy cannot be observed directly.

The most general and popular definition of entropy is associated with disorder.

The first law of thermodynamics, the Conservation of Energy, is a fundamental law. We can write this law as “the energy change of a system during a process is equal to the energy interaction of the system.” However, the same consideration does not apply to entropy. During a process, the entropy change of a system is greater than or

equal to the entropy interaction of the system. This equality applies only to ideal processes. Therefore, in real processes, the entropy change of the system is greater than the entropy interaction of the system. The difference is always positive and equal to the entropy production.

The second law of thermodynamics, or the principle of increasing entropy, demonstrates that processes are irreversible; in other words, they are not (spontaneously) reversible. Life and all life-related processes are irreversible. For example, these include natural processes, such as the oxidation of metals, as well as technical processes, such as the combustion of fossil fuels in internal combustion engines or the production of metals from ores. The concept of entropy, introduced in thermodynamics to reflect this natural reality, allows for quantitative expressions about the efficiency of energetic and material transformations.

The importance of entropy is that it can quantify irreversibility.

The more concentrated the energy, that is, the lower its entropy, the more likely we are to do work with it. The more dispersed the energy, that is, the more increased its entropy, the less likely we are to do work. For example, we can't generate energy from randomly scattered puddles of water on Earth's surface. Still, we can do meaningful work by collecting water on one side of a dam and letting it flow in a controlled manner to the other side, thereby generating the electrical energy we need.

All human activity increases entropy, but many of the things we do are also helpful, improving our quality of life and making our work easier. By using the concept of entropy, we can make these activities less irreversible. Therefore, we can also define entropy as "meaningful disorder."

Entropy production measures the irreversible loss of energy and the dissipation of matter, a key physical constraint on achieving global sustainability goals. In this context, recycling represents an opportunity.

Entropy and Recycling

Both natural and anthropogenic systems (e.g., industrial systems) essentially operate as entropy production mechanisms, converting primary natural resources (with low entropy) into waste (with high entropy). Humans recycle their waste to reduce the environmental impact of their systems. However, every human activity, including those aimed at recycling, causes global entropy to increase. According to this approach, entropy can be a measure of the environmental sustainability of anthropogenic systems, meaning that the greater the entropy produced by human activities, the greater their environmental impact.

Is aluminium scrap waste or a new raw material?

According to 2023 data from the International Aluminium Institute (IAI), the global average electrical energy consumed per tonne of primary aluminium in the electrolysis process alone was 13.2 kWh/kg Al. 67% of this energy came from fossil fuels, releasing 16.6 t CO_{2e} per tonne of aluminium into the atmosphere. However, because aluminium metal behaves as an energy bank, the embodied energy stored in the primary production process allows recycling processes to consume between 5% to 8% of the primary production. The same relationship applies to CO_{2e} emissions. Globally, the average CO_{2e} emission from aluminium recycling processes is 0.6 t per tonne of aluminium according to the IAI and 0.5 t according to Hydro.

In other words, when we approach waste as a “new raw material,” the environmental damage will be more manageable because a lower amount of entropy will be produced.

The recycling process allows the production of secondary products with lower entropy as a result of mechanical and thermal processes, as scrap has become complex, worn out and disordered. In other words, recycling is an important tool in the challenge to reduce entropy.

If a material is recycled into a lower-quality product, entropy increases (downcycling). The material loses some of its original order and value, making it difficult to return it to its original high-quality state. Consequently, more efficient recycling processes and less recycling can lead to lower entropy in the overall system, leading to reduced energy consumption, reduced waste and improved resource utilisation. Therefore, sustainable practices aim to minimise entropy as much as possible and maintain a closed material cycle (upcycling).

Conclusions

When one understands the concept of entropy, the increase in chaos within a system and the role technology plays in it, both climate change and resource depletion take on new meaning. Entropy is what unites everything we do to this planet: we consume all the low-entropy, high-value resources and convert them into high-entropy (well-diluted) pollution and waste heat.

Future materials management systems will prioritise reducing the entropy cost of recycling. With today’s technological advancements, we have many tools at our disposal to avoid downcycling and achieve upcycling. In other words, we can create a digital ecosystem for secondary aluminium production.

Even after recycling processes that attempt to reduce entropy, achieving original perfection is impossible because there is constant disorder in the system. In other words, it is impossible to meet all primary aluminium needs from secondary

sources. However, every gram of primary aluminium substituted for secondary material will make a significant contribution to achieving sustainability goals.

Source: AL Circle Blog, 21 November 2025

Odisha to Auction 3 Gold Bearing Mineral Blocks

For the first time, three gold-bearing mineral blocks of Odisha will go under the hammer. The three blocks are part of 34 mineral blocks - 25 major mineral blocks and nine critical and strategic mineral assets - that the state government has lined up for auction in the financial year 2026-27 (FY27)

Odisha is among nine states where the Geological Survey of India (GSI) had detected gold deposits earlier. According to the Indian Minerals Yearbook 2022, the largest resources are located in Bihar (43 per cent), followed by Rajasthan (24 per cent), and Karnataka (20 per cent). Thirty-four mineral blocks in Odisha are spread across 12 districts - Mayurbhanj, Keonjhar, Sundargarh, Balangir, Rayagada, Koraput, Nuapada, Nayagarh, Deogarh, Kalahandi, Subarnapur, and Malkangiri, covering a wide spectrum of mineral resources.

The gold blocks identified for auction are Jaldihi in Keonjhar, spanning 150 hectares (ha) with exclusive gold deposits, Madan-sahi-Kanjia in Mayurbhanj, spread over around 300 ha with copper and gold deposits, and Adash-Rampali in Deogarh with an area of 110 ha.

All the three blocks have undergone G2- level exploration and detailed assessment of mineralization zones. The Adash-Rampali block is estimated to contain around 0.9 million tonnes (mt) of gold, in addition to 8.16 mt of copper, 0.99 mt of graphite, 0.63 mt of silver, and 0.1 mt of nickel. G2-level exploration, or general exploration, is the third stage in the mineral exploration hierarchy (following G4 and G3) designed to establish the main geological features, shape, size, and grade of a mineral deposit.

Sources said the 25 major mineral blocks up for auction include five iron ore blocks, six bauxite blocks, four iron ore and manganese blocks, three quartz blocks, two limestone blocks, and one block each of manganese, copper, and composite deposits such as gold, iron ore with aluminous laterite, and iron ore with bauxite. Among the nine critical and strategic mineral blocks, there are two standalone graphite blocks, three blocks with a mix of manganese and graphite, one composite block containing manganese, graphite and vanadium, one polymetallic base metal block with copper, nickel, gold, and silver, and one block each of graphite and tin.

Source: Business Standard

Critical Mineral Auction

Seventh tranche of e-auction for critical and strategic mineral blocks has been launched in the country, expanding efforts to secure key resources for emerging and strategic sectors.

The blocks on offer include rare earth elements (REE), tungsten, lithium, graphite, vanadium, titanium, glauconite and rock phosphate—minerals vital for clean energy technologies, advanced manufacturing, fertilisers and strategic applications.

The blocks are spread across Arunachal Pradesh, Bihar, Chhattisgarh, Gujarat, Karnataka, Madhya Pradesh, Odisha, Rajasthan, Telangana and Uttarakhand.

Geothermal Energy

Geothermal energy is a promising and versatile renewable energy resource with vast untapped potential for electricity generation, heating and cooling. Geothermal energy is the thermal (heat) energy derived from the Earth's subsurface. Part of this energy is residual heat generated during the planet's formation (i.e. from planetary accretion and the decay of short-lived radioactive isotopes) more than 4 billion years ago. The rest originates mostly from the continuous and spontaneous radioactive decay of naturally occurring isotopes (e.g. uranium 238 and 235, thorium 232 and potassium 40) within the Earth's core and mantle, which maintains the core temperature at around 5000°C. This heat from the core and mantle is transferred to the Earth's surface through conduction (heat passing through materials) as well as convection and advection mechanisms (heat being transported by a moving fluid – e.g. magma), resulting in a continuous heat flow of about 45 TW across the surface of the globe. Another portion of the Earth's thermal energy comes from solar radiation at the surface and from ambient heat absorbed and accumulated over millennia, which influences the temperature of soil, bedrock and water at shallow depths everywhere on Earth. The temperature difference between the Earth's core and surface induces a temperature gradient in the crust: on average, the temperature increases 25-30°C per kilometre of depth. However, geothermal heat-flows and temperature gradients are unevenly distributed and are strongly linked to tectonic conditions, including volcanic activity at spreading centres, rift zones, subduction zones and hot spots, as well as crustal extension (with thinner crust). These circumstances can lead to regionally elevated temperatures in the crust, and temperatures can also be higher in areas with extensive sediment-covered granitic intrusions, due to heat produced from radioactive decay. Geothermal energy

systems harness this heat from the subsurface and transport it to the surface, where it can be used for heating and cooling, electricity generation and energy storage. Geothermal heat can be carried to the surface by fluids naturally occurring in the subsurface in specific geological settings such as aquifers, where water trapped in porous or fractured rock beneath a layer of relatively impermeable caprock forms a reservoir and is heated by the surrounding rock. Temperature, fluid and rock permeability conditions define hydrothermal resources. The systems used to exploit these hydrothermal reservoirs are what is termed as conventional geothermal technologies.

Efforts to overcome dependency on location-specific hydrothermal resources have led to the development of new approaches that harvest heat at greater depths by circulating a fluid from the surface through engineered systems, either through fractured rock or in closed-loops circuits, sometimes in areas that have no preexisting hydrothermal reservoir. These approaches, also termed reservoir-independent, are more recent and generally less mature, and are therefore referred as next-generation geothermal technologies. Overall, they include enhanced geothermal systems (EGSs) and closed-loop geothermal systems (CLGSs), with the latter sometimes also referred to as advanced geothermal systems (AGSs).

In addition, low-temperature heat can be transferred from and to the near-surface (<100m of depth) using **ground-source heat pumps** – also called **geothermal heat pumps** – to supply a variety of applications with low- and medium temperature heat (generally below 200°C) or cooling.

Unlike for other renewable energy sources such as wind, solar and hydro, geothermal energy production does not depend on climatic conditions or seasonality. It can be used in direct applications (for space and water heating and cooling, or for industrial processes) or for electricity generation, with different technologies (e.g. binary, flash and dry steam plants) depending on the geothermal resource conditions (temperature, pressure of the reservoir) and properties (e.g. reservoir geology, permeability/porosity, heat transfer conditions); the chemical properties of the fluid; and whether the fluid is in vapor or liquid phase in the system. However, several challenges must be addressed to successfully scale up geothermal energy development.

Geothermal power plants use heat from the geothermal fluid to power a turbine that turns a generator to produce electricity. The heat-depleted geothermal fluid is then reinjected into the reservoir, where it collects heat again. Binary-cycle power plants circulate the geothermal fluid through a heat exchanger to heat and vaporise a second fluid that flows through the turbine to produce electricity (generally using a

closed-loop Rankine cycle). Flash steam power plants process the geothermal fluid to separate steam from water, before flowing the steam through the turbine to generate electricity. Dry steam power plants inject geothermal steam that is above the saturation point of water directly into the turbine to generate electricity, without needing to separate water from steam. Binary plants can operate with fluids at lower temperatures than flash and dry steam plants (from ~95°C versus more than ~180°C), but they also have lower conversion efficiencies and generally higher investment costs.

Technology breakthroughs are unlocking huge potential for geothermal energy, promising to make it an attractive option for countries and companies all around the world. These techniques include horizontal drilling and hydraulic fracturing honed through oil and gas developments. If geothermal can follow in the footsteps of innovation success stories such as solar PV, wind, EVs and batteries, it can become a cornerstone of tomorrow's electricity and heat systems as a dispatchable and clean source of energy. For the moment, geothermal meets less than 1% of global energy demand and its use is concentrated in a few countries with easily accessible and high-quality resources, including the United States, Iceland, Indonesia, Türkiye, Kenya and Italy. With continued technology improvements and reductions in project costs, geothermal could meet up to 15% of global electricity demand growth to 2050. This would mean the cost-effective deployment of as much as 800 GW of geothermal power capacity worldwide, producing almost 6 000 terawatt-hours per year, equivalent to the current electricity demand today of the United States and India combined.

Geothermal is a versatile, clean and secure energy source. Geothermal can provide around-the-clock electricity generation, heat production and storage. As the energy source is continuous, geothermal power plants can operate at their maximum capacity throughout the day and year. On average, global geothermal capacity had a utilisation rate over 75% in 2023, compared with less than 30% for wind power and less than 15% for solar PV. In addition, geothermal power plants can operate flexibly in ways that contribute to the stability of electricity grids, ensuring demand can be met at all times and supporting the integration of variable renewables such as solar PV and wind. The potential for geothermal is now truly global. The full technical potential of next-generation geothermal systems to generate electricity is second only to solar PV among renewable technologies and sufficient to meet global electricity demand 140-times over.

Geothermal energy potential increases as developers access higher heat resources at greater depths. New drilling technologies exploring resources at depths beyond 3 km open potential for geothermal in nearly all countries in the world. Using thermal

resources at depths below 8km can deliver almost 600 TW of geothermal capacity with an operating lifespan of 25 years. Geothermal can also provide a continuous source of low- and medium temperature heat for use in buildings, industry and district heating. Global geothermal potential from sedimentary aquifers at depths up to 3 km and temperatures greater than 90°C is estimated around 320 TW. This is consistent with the requirements of existing fossil fuel-fired district heating networks, which could be decarbonised by switching to geothermal heat. For lower temperature requirements, the potential for geothermal increases about tenfold. The technical potential of geothermal would be more than enough to meet all electricity and heat demand in Africa, China, Europe, Southeast Asia and the United States. Geothermal holds particular promise in markets with rapidly rising electricity demand by complementing output from other low-emissions technologies such as renewables and nuclear power while also bolstering energy security

Source: The Future of Geothermal Energy, IEA Report

Indirect Trade in Steel

Indirect trade in steel takes place through exports and imports of goods that contain steel. These goods are classified in six categories: automotive, other transport, domestic (household) appliances, mechanical machinery, electrical equipment and metal products.

To process the indirect trade in steel calculations, it is necessary to count how much steel went into producing each manufactured product, namely the *steel coefficients* of each product, expressed in terms of the weight of the product. Steel coefficient is the amount of finished steel products (in metric tons) needed to produce one ton of a manufactured product.

When gathering trade data, Worldsteel adopts the *Harmonized Commodity Description and Coding System (HS) of the United Nations* to define traded goods.

Cross-border trade in steel-containing products continued to grow in 2024, according to the World Steel Association (Worldsteel).

From 2014 to 2024, indirect exports of steel increased by 26 percent from 325 million metric tons (mmt) in 2014 to 410 mmt in 2024. The calculated volume of the cross-border trading of steel-containing products, referred to as the indirect trade of steel, checked in at 93 percent of the volume of the direct exporting of finished and semifinished steel in 2024.

Source: World Steel Association

Aluminium Production: Energy Efficiency is about Fixing the Leaks before Worrying about the Source

For aluminium and metals producers, power is often the single largest cost input.

A very large share of the raw material cost is energy, and in smelting, it is almost entirely electricity. In many primary aluminium operations, 60–70 per cent of the cash cost is effectively the power bill. So volatility in power prices directly translates into volatility in margins.

In Europe in 2024, several smelters saw their margins completely wiped out because power prices spiked faster than aluminium prices could adjust. They were technically producing, but not profitably.

The second, more structural issue is the physical lock-in. A smelter is not like a cement plant that we can ramp down at will. If there is no power for roughly 75 minutes, the molten aluminium in the pots starts to solidify. It happened at the Portland Aluminium smelter in Australia in 2016. Restarting after that kind of incident can take months and cost hundreds of crores.

So producers are not just exposed to the *level* of electricity prices, but also forced to keep drawing power through peaks to avoid a catastrophic freeze. That makes the sector structurally very sensitive to both short-term spikes and long-term shifts in energy prices.

With aluminium being a baseload, power-intensive industry, realistic large-scale renewable integration without compromising operational stability is challenging, because aluminium needs absolutely firm 24×7 power, and wind and solar by nature are intermittent. A straightforward shift to only solar or only wind is not realistic for a smelter.

The first step is obviously hybrids—wind plus solar—because their generation profiles are complementary. But even with a good hybrid, you still don't control how a particular day behaves. You can forecast, but you cannot guarantee that “X megawatts” of green power will show up exactly when the smelter needs it.

That's where battery storage comes in. A wind-solar-BESS combination can give you much better reliability, but the quantum of storage needed to truly cover a 24×7 baseload smelter is huge and currently uneconomical. Where batteries make more sense today is in time-of-day applications.

For example, evening tariffs between 6 and 8 pm are high in states like Maharashtra, Tamil Nadu or Rajasthan. You can charge batteries in the daytime with cheaper solar

and discharge them during those peak hours – classic peak shaving for 2–4 hours. As storage costs fall further, this becomes increasingly attractive.

But for true baseload in India today, aluminium remains largely coal-based. A realistic path is a portfolio: coal for firm baseload, plus a growing share of solar, wind and BESS to shave peaks, reduce overall emissions and gradually increase the renewable fraction.

In aluminium smelting and downstream metal processing, the single biggest untapped lever is cell optimisation. That's where you can unlock significant energy savings and meaningful reductions in specific emissions per tonne.

With CBAM now in force, cell-level efficiency directly links to competitiveness. But most Indian smelters were commissioned decades ago—1960s, 70s vintages—and each has different technology. Vedanta's lines are not identical to Nalco's or Balco's. That lack of standardisation makes it harder to roll out one common optimisation solution at scale.

So while the technical potential is large, the reality is: you need plant-specific engineering, and that takes time, money and confidence in the technology.

The second big area is electrolysis waste-heat recovery. There is a lot of low-grade heat that can be captured and either reused or used to reduce overall energy draw. These kinds of retrofits and smarter control systems typically have paybacks in the 3–5 years range, which is quite attractive for heavy industry.

Many of the other, more conventional efficiency measures have already been tackled under India's PAT cycles, and now we are moving into CCTS from April 2026. NITI Aayog's own roadmap recognises energy efficiency as a core pillar of aluminium decarbonisation. But efficiency rarely makes headlines. A 500 MW renewable announcement is a front-page story; a 5 per cent reduction in specific kWh per tonne shows up quietly on the balance sheet. And because efficiency retrofits touch core operations, management is understandably more cautious than with an offsite solar PPA.

In an industrial decarbonisation roadmap, you need to balance energy-efficiency interventions against renewable energy additions.

If you're filling a bucket that has leaks, it doesn't matter whether the water is coming from the purest Himalayan spring or from a regular tap—you're still wasting water. In our context, energy efficiency is about fixing the leaks before you worry about the source.

So, the first step has to be efficiency, because it's usually the quickest and the most cost-effective. With large metal companies, well-designed efficiency projects

typically pay back in 18–24 months, and in some complex cases maybe 24–36 months. Renewables are also absolutely necessary, but the payback tends to be longer and they mostly displace a portion of the fossil power, they don't eliminate it.

The big plus for renewables is that they sit outside core operations. You are not opening up your potline; you are changing the source of electrons through a rooftop plant or an offsite PPA. So operational risk feels lower.

However, we should be realistic: you cannot move an aluminium smelter to 100 per cent variable renewables with today's technology. You will always need some firm power—today, that's largely coal; tomorrow, it can be nuclear or gas-plus-CCUS—backing the baseload.

That's why nuclear power is important, especially small modular reactors. The upcoming SMR policy can allow nuclear to cover, say, 60–70 per cent of the baseload, with the remaining 30–35 per cent coming from solar, wind and batteries. If you combine that kind of mix with serious efficiency and smart load modulation at the smelter, deep decarbonisation becomes technically and economically achievable.

Battery storage and hybrid systems are increasingly discussed for metals plants.

Batteries are at the stage where solar was around 2009–10: still relatively expensive, but on a very clear cost-down curve and already compelling in some use cases.

In the last decade, battery prices have fallen by almost 90 per cent globally, and in India we've seen tariffs for solar-plus-4-hour storage drop to roughly ₹2.7 per unit, with over 50 bidders entering these tenders. This year we expect that to soften further towards ₹2.5–2.4 per unit. That's a dramatic shift.

On the technology side, we're also moving beyond only lithium-ion into chemistries like sodium-ion, which may be bulkier but are well-suited to large industrial campuses where space is not the main constraint.

Where storage really makes sense today for metals is for peak shaving and firming, not for full baseload replacement. Using 2–4 hours of BESS to clip evening peaks, back up solar and arbitrage time-of-day tariffs is already economically attractive in many states. Using batteries to carry an aluminium smelter overnight for 8–10 hours straight is still very capital intensive.

So, in practical terms, hybrids can be used as a surgical tool—firming, peak management, and improving the effective share of renewables—rather than as a standalone answer to baseload for aluminium.

With CBAM and similar mechanisms tightening globally, are Indian aluminium and metals producers moving fast enough on measurable decarbonisation?

In simple terms, no. Progress is happening, but if you look at where we need to be for CBAM, we are still behind the curve.

India's aluminium sector sits at an average emission intensity of about 20–21 tonnes of CO₂ per tonne of metal, versus a global average closer to 15. That's a big gap in a world where carbon is now a priced commodity. Some international producers have already brought a large share of their power from renewables and hydro, and optimised their cell operations and digital controls, so their intensity is materially lower.

Indian producers have started moving—there is work happening on cell optimisation, digitalisation, and on adding renewables and even pumped hydro into the mix—but it's from a high baseline. The “big four” have collectively talked about building up to 20 GW of renewables by 2030, backed by about 5 billion dollars of investment. That's a strong signal of intent.

The challenge is two-fold: first, that 20 GW is not just for running the pots, it also depends on significant upgrades to grid infrastructure and evacuation capacity. Second, CBAM is on a very tight timeline; the mechanism is already live, and effective carbon costs in Europe are not trivial.

If Indian metal producers want to be CBAM-ready, they will have to move faster on three fronts simultaneously: deep efficiency inside the plants, serious and verifiable low-carbon power, and smarter, collective infrastructure planning. A coordinated, bulk approach by the big players on renewables and transmission—rather than everyone going alone—would help a lot. Otherwise, we risk having announced capacity on paper that cannot be fully utilised in time for CBAM.

Source: AL Circle Upstream Newsletter, 14 November 2026

Methane: Why It Matters, and How to Tackle It

Preventing methane emissions is one of the fastest ways we can slow Earth from overheating right now. Methane isn't just a damaging waste product, it is also a valuable commodity that is marketed as “natural gas,” which is produced alongside oil. When it leaks into the atmosphere, however, methane massively traps heat and warms our planet at an accelerated rate.

Methane was discovered in Italy 250 years ago due to bubbles arising from marshes. When collected and ignited, methane lit on fire and was initially called “swamp gas”. Although methane (chemical name CH₄) has been steadily present in the Earth's atmosphere at low levels for tens of thousands of years, its volume has increased dramatically since the Industrial Revolution due to increased fossil fuel

use, agricultural expansion, and landfill development. In 2025, methane levels were at the highest ever recorded.

This increase in methane accounts for a roughly 0.5°C increase in global temperature, or nearly 30 percent of “forced” or human-made warming to date, which makes tackling methane pollution a pressing climate concern.

What makes methane so dangerous?

While carbon dioxide acts like a heat-trapping blanket around our planet, methane acts like an electric blanket with much more warming power. Methane has a lifetime of about a decade before it reacts to form other climate gases. Over a 20-year span, methane is over 80 times more powerful than carbon dioxide at warming the planet. As methane and other greenhouse gases build up at today’s elevated levels, their “blanketing” effect traps far too much heat. The greater the buildup, the greater the risk of life-threatening, property damaging, and costly extreme weather, wildfires, flooding, and other harms.

As well as being a climate concern, methane also causes substantial problems on the ground. Methane contributes to the formation of ground-level ozone, known as smog. Methane is also co-emitted with deadly contaminants and air toxins that kill and sicken people near where it is released. For example, benzene, a known carcinogen, can accompany methane when gas leaks from wells, flares, tanks, pipelines, chemical plants, and furnaces. Deadly hydrogen sulfide can be co-emitted with methane from oil and gas wells. And super-emitting methane sources that are present in very large volumes can explode and cause fires.

What are the main sources of methane?

The fossil fuel industry, landfills, livestock, and agriculture are the major human-made sources of methane, making up about 55 percent of current methane pollution. Natural sources, like wetlands, swamps, and thawing permafrost, produce roughly 45 percent. Different places have different shares of methane.

Methane is invisible, usually odourless, and under high pressure. This means it can readily leak in every stage of the oil and gas supply chain. It is easily emitted from landfills when food and other organic waste decompose. Some crops release methane as they grow. And animals, like cattle, expel it as a waste product.

How can we cut emissions?

The best place to slash methane is to start where we can make the most immediate impact. Methane from fossil fuels is a prime target because the methane in gas is a valuable commodity that is widely traded. Preventing gas from escaping means that

companies can recoup money and prevent exposure to harmful impacts. Stopping leaks, reducing venting, and limiting flaring can quickly cut energy waste and curb methane emissions.

For landfills, a suit of tools is available to stop methane pollution at waste sites. These include reducing food waste, diverting food waste from the waste stream away from the disposal sites to anaerobic digesters or composting facilities, improving landfill cover practices, and enhancing gas capturing efficiency.

Cutting methane from livestock involves changes to waste handling and animal diets. Promising experiments are taking place with novel cattle feeds that reduce overall emissions. And reducing methane emissions from agriculture calls for changes to cultivation practices and other new control methods.

As a backstop, there is also work underway to study methane removal. As this powerful greenhouse gas builds up in the atmosphere, there may be a role to develop methods in the future for its removal in addition to efforts underway to cut methane emissions in each sector.

How can data accelerate action?

To tackle leaks and ultimately prevent them *before* they happen, we need to make invisible methane visible. This requires sensors and checks on the ground to make sure equipment is working as it should, as well as aerial surveys and even satellites to catch leaks as they happen.

Data-to-action efforts involve updated infrastructure, improved monitoring, and tighter regulations to enable faster responses to unexpected events that can reduce methane releases. The greatest opportunities in tackling methane emissions lie in more accurately measuring the emissions and reducing reliance on the industry's self-reported emissions, which leads to emissions undercounting.

What is being done at the international level to prevent methane pollution?

Countries at COP26 in 2021 signed on to the Global Methane Pledge, which calls for a 30 percent reduction in 2020 methane levels by 2030. The 159 country signatories currently represent roughly 50 percent of the total methane emitted today.

Other initiatives involve incentivizing the production of low-methane oil and gas. The European Union's methane regulations, which came into force in 2024, apply strict measures, including bans on venting and flaring and a low-methane standard that gas importers must meet.

What are the benefits from reducing methane?

Methane has a much shorter lifetime in our atmosphere than carbon dioxide. This means that reducing methane now immediately prevents it from warming Earth in the short term. Methane also takes longer to react into dangerous air pollutants, like smog. Any action to prevent or more quickly stop methane leakage protects our health and safety. Rapidly attending to large methane plumes and preventing explosions can prevent risk to people and property.

Driving down methane emissions buys us crucial time to accelerate new technologies and scale the energy transition. Cutting methane means a cooler planet, a healthier environment, and clearer skies — and wasting fewer energy sources.

Source: RMI Spark, 05 March 2026

Japanese Steel Mills and the Australian Coking Coal industry

The symbiotic rise of the Japanese Steel Mills and the Australian Coking Coal industry represents one of the most significant structural shifts in 20th-century metallurgy. This "tango" redefined global benchmarks and established the modern standards for coke quality.

Following WWII, Japan adopted a high-growth strategy centered on massive blast furnaces. This required a stable, high-volume supply of premium metallurgical coal that traditional domestic and US sources could not sustainably provide at scale.

Australia's proximity to Japan offered a permanent "freight advantage." The development of dedicated deep-water ports (e.g., Hay Point) and high-capacity rail in Queensland allowed for the world's most efficient "mine-to-mill" supply chain.

Unlike traditional arms-length trade, Japanese trading houses and steel giants (Nippon Steel, JFE) took direct equity stakes in Australian mines (e.g., Bowen Basin), securing supply while providing the capital needed for Australia's open-cut mining revolution.

The adoption of CSR (Coke Strength after Reaction) and CRI (Coke Reactivity Index) by Nippon Steel in the late 1970s was the pivotal technical turning point. Traditional "cold strength" metrics (Micum/Tumbler) failed to predict coke performance in large BF's. The CSR test proved that Australian "Hard Coking Coals" (HCC) maintained structural integrity at high temperatures far better than global competitors.

This technical standard effectively commoditized the Australian specification, forcing the rest of the world to adopt Australian HCC as the global price and quality benchmark.

The predictability of Australian coal properties allowed for "Scientific Blending,"

where high-CSR Australian coal acted as the skeleton, enabling the use of cheaper, lower-rank "Semi-Soft" coals. High-CSR coke permitted higher Pulverized Coal Injection (PCI) rates and lower coke rates, drastically reducing the cost per ton of hot metal (THM).

The "tango" is currently facing its most significant challenges since the 1960s: Decarbonization & Hydrogen. The shift toward Green Steel (Hydrogen-based Direct Reduced Iron or HDRI) threatens the long-term necessity of coking coal. Projects like NSC's COURSE50 focus on reducing CO₂ rather than just maximizing CSR.

New research into CAI (Coke Activity Index) and CPI (Coke Post-reaction Index) suggests that traditional CSR/CRI may no longer be sufficient to describe coke behavior in the hydrogen-rich atmospheres of the future.

The transition from Micum/Tumbler indices to CSR- CRI metrics beautifully illustrates how aligning coke characterization with the actual thermochemical environment of the blast furnace reshaped both furnace practice and global coal economics. Once post-reaction strength became central, coal selection and blending strategies across the world began revolving around that behaviour.

What makes the current phase even more intriguing is the emerging research on hydrogen-enriched blast furnace atmospheres, where higher H₂O levels may accelerate coke gasification and alter degradation mechanisms. This perhaps explains the growing interest in new indices such as CAI/CPI, which attempt to capture coke behaviour under evolving reduction environments. It will be fascinating to see whether these developments redefine the performance benchmarks that have guided blast furnace practice for decades.

Terminologies like hard, soft, semi hard or semi soft were attributed by the Japanese based on their assessment on the commercial value of each (*Ref. Australian Standard on Coal, Coke Terminologies*).

The link between high-CSR coke, scientific coal blending, and improved PCI rates clearly shows how process optimization reduced hot metal costs. It will be interesting to see how upcoming hydrogen-based steelmaking technologies redefine coke quality parameters.

Source: LinkedIn Post

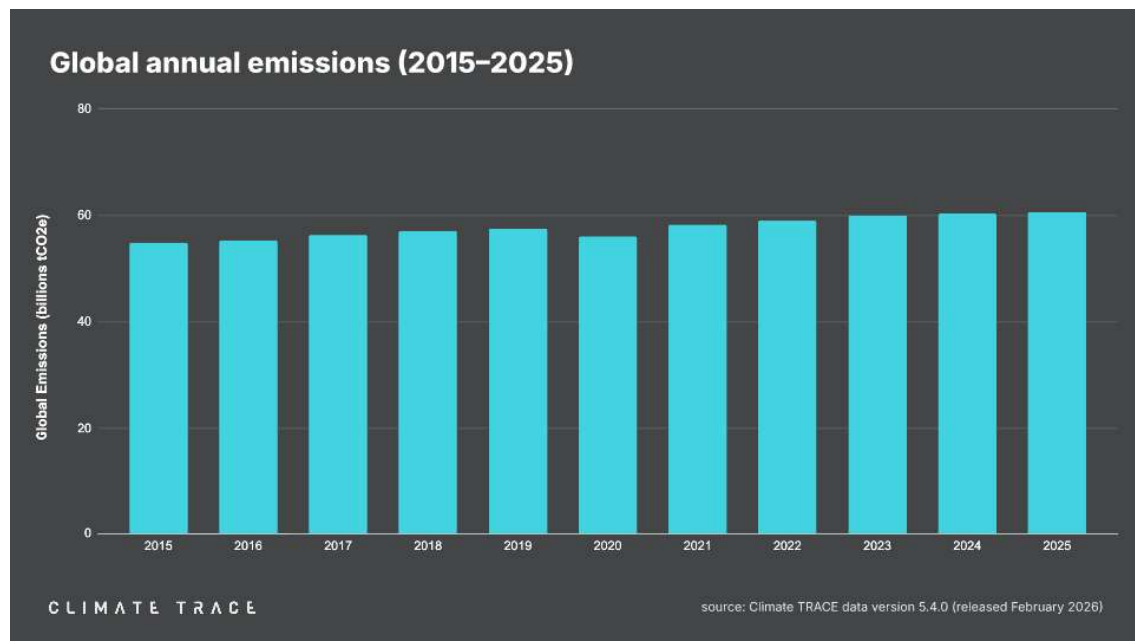
Global Greenhouse Gas Emissions in 2025

Climate TRACE released full-year 2025 emissions data, showing that global greenhouse gas (GHG) emissions increased 0.50% by 303.19 Mt CO₂e last year,

reaching a new high of 60.63 Bt CO₂e. Global methane emissions increased 1.03% or 4.2 Mt CH₄ in 2025, rebounding from a decline in 2024 to set a new annual record of 412.59 Mt CH₄, surpassing the previous record set in 2023.

Key Insights from 2025 Emissions Data:

- Despite a small decline in power sector emissions, fossil fuel operations, transportation, manufacturing, and buildings all nudged global greenhouse gas emissions higher.
- Oil and gas production was the subsector with the largest jump in emissions, increasing 4.1%.
- The biggest movers in the power sector were China, India, and the US. For the first time since at least 2015, emissions from China's power sector decreased year over year, but that decline was offset by an equivalent increase in US power emissions. Meanwhile, India's power sector emissions fell for the first time since 2020.
- Road transportation emissions increased globally, but have dropped in Nordic countries where electric vehicle (EV) adoption is high.



Global Trends

Climate TRACE data show that in nearly every month of 2025, global emissions were higher than they were in 2024.

Top 10 Countries by Total 2025 GHG Emissions			
Country	Total GHG Emissions	Absolute Change vs. 2024	Percentage Change vs. 2024
 1. China	17.4 Bt	48.8 Mt	0.28%
 2. United States	7.0 Bt	16.2 Mt	0.23%
 3. India	4.22 Bt	-27.5 Mt	-0.65%
 4. Russia	3.2 Bt	51.6 Mt	1.64%
 5. Indonesia	1.55 Bt	13.2 Mt	0.86%
 6. Brazil	1.38 Bt	19.5 Mt	1.43%
 7. Iran	1.28 Bt	-1.1 Mt	-0.09%
 8. Japan	1.28 Bt	-5.3 Mt	-0.41%
 9. Saudi Arabia	1.05 Bt	22 Mt	2.14%
 10. Canada	0.95 Bt	0.34 Mt	0.04%

CLIMATE TRACE source: Climate TRACE data version 5.4.0 (released February 2026)

In 2025, Russia's emissions increased the most of any country in the world, while India had the largest drop in emissions. China and the United States, the world's top two emitters, saw their emissions stay relatively flat in 2025, ticking up slightly in each country.

Across 10 major emitting sectors, the most significant growth in emissions in 2025 came from fossil fuel operations, with emissions rising 1.56% or 151.57 Mt CO₂e. Emissions also rose in the transportation, manufacturing, and buildings sectors last year.

The power sector continues to be the largest source of global emissions in 2025 (26% of total emissions). Climate TRACE data show that global power sector emissions fell slightly, decreasing by 0.13% or 20.31 Mt CO₂e in 2025 --- the first decline since the COVID-19 pandemic. Most of the decline came from electricity generation in India and China, but Russia, Australia, and Poland also saw significant drops in their power sector emissions.

Globally, the current rate of growth in emissions is half of what it was throughout the rest of the decade, slowing from an average 1.1% increase each year between 2015 and 2023 to an average of 0.5% increase over the past two years. Excluding 2020, the past two years saw the slowest growth in emissions since 2015, the year of the Paris Agreement.

Spotlight on China and the US

China and the United States continue to be the first and second largest sources of emissions, by country.

Clean power in India and China

In the past decade, China and India led the world in growth in power sector emissions. China's power sector emissions increased 53.7% between 2015 and 2024, while India's increased 34.6% in the same period. But last year, that rapid growth stalled. In 2025, China's power sector emissions fell 0.4%, the first time Climate TRACE data has shown a decline since the beginning of our inventory in 2015. India's power sector emissions fell for the first time since 2020, dropping 2.6% last year.

Crucially, both of these declines come at a time of increased economic growth and electricity consumption, demonstrating that renewable deployment is beginning to make a dent in overall power sector emissions in these countries.

EV adoption in Nordic countries

Globally, road transportation emissions have increased significantly over the past decade, but that is not the case in the Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden). Since 2015, road transportation emissions in the Nordics have declined by 6.2%, whereas road transportation emissions have increased 3.8% in the EU and 11.2% globally. This is likely because the Nordic nations have seen strong EV adoption over the past decade. On average, nearly 70% of new car sales in these countries are electric. In Norway, where EVs comprised 96% of new car sales in 2025, road transportation emissions have dropped by nearly 9% in the past decade and fell by 2% last year alone.

The Nordic countries also made significant progress in cleaner power alongside EV adoption, with electricity generation emissions declining by 55.9% since 2015, outpacing the EU's 44.8% reduction.

Source: Climate TRACE Data Releases Feb 26, 2026

Government Cancels Auction of 11 Critical Minerals Blocks

The government has cancelled the auction of 11 critical and strategic mineral blocks, which were put on the block in the sixth round, on account of poor investor response and lack of qualified bidders.

IIT Khargpur PRL Team Decodes Moon's Ti-Rich Rocks

While volcanic rocks on earth rarely contain more than 2% titanium dioxide, some lunar basalts carry up to 18%, a fact planetary scientists have struggled to explain.

New work by IIT Kharagpur and Physical Research Laboratory, Ahmedabad, published recently in *Geschimica et Cosmochimica Acta*, has offered one explanation.

ISRO's Chandrayaan-4 mission will collect lunar rock samples and return them to earth. The study's findings could help inform the choice of landing site by identifying locations carrying the chemical fingerprints of the moon's interior.

High-resolution microscopic cameras on landers can help identify minerals in lunar rocks, while instruments such as X-ray fluorescence and X-ray diffraction can determine their chemical composition before collection. Spectroscopic tools such as Raman and visible near infrared spectroscopy can help confirm the mineral phases in rocks before they are collected.

Some 4.3 billion years ago, the moon was cooling from a global ocean of molten rock. Minerals called olivine and orthopyroxene crystallized first, then plagioclase, and finally the titanium-rich ilmenite-bearing cumulate (IBC) layer.

IBC was dense. As it sank through the magnesium-rich mantle, it heated up and melted. The resulting titanium-rich partial melts are believed to be the source of the moon's titanium-rich basalts, but the act mechanism has been contested.

In one set of experiments, the team placed a thin synthetic IBC layer above a mix of minerals resembling the moon's mantle, inside an apparatus that could mimic the extreme conditions where the sinking layer met the mantle. In a second set, the team blended the materials together and exposed them to similar conditions.

The results suggested that basalts high in titanium were created in a complex process involving both reactions and mixing. The first set of tests yielded melts high in titanium dioxide but low in magnesium oxide while the second set produced basalts too rich in magnesium and too low in titanium. When the team simulated a combination of these processes, they found some molten rocks could have risen and erupted with moderate amounts of titanium while those rich in titanium could have become stuck inside the moon. Later, fresh magma rising from below could have mixed with these trapped pockets and the combined mass could have erupted as titanium-rich lava.