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Nugget Global

Research, Commercialization, Market, and Leadership In Green and Low-Carbon Metals: Adoption, Adaptation, and Transition

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Background

The green and low-carbon metals sector is rapidly evolving, driven by the global push for decarbonization and sustainable practices. Here's an overview of recent developments in research, commercialization, market trends, and key industry leaders:

1. Research and Innovation

Boston Metal – Molten Oxide Electrolysis (MOE) (https://www.bostonmetal.com/wp-content/uploads/2025/04/critical-metals-animation-en-20250410.mp4)

Boston Metal has pioneered a zero-emission steelmaking process called molten oxide electrolysis (MOE). This method uses renewable electricity to extract steel from iron ore without generating CO_2 emissions. The company has secured $262 million in funding from investors like Aramco Ventures and Microsoft's Climate Innovation Fund. Its first commercial application launched in Brazil, with plans to license the technology for "green steel" production by 2026.

MOE Process: MOE involves heating a molten electrolyte containing metal oxides to a high temperature (e.g., 1600°C) using electricity. This electricity drives a chemical reaction that separates the metal from the oxide, producing pure liquid metal.

Benefits:

- **Reduced Carbon Emissions:** MOE can significantly reduce or even eliminate carbon emissions, especially when using renewable electricity sources.
- **Simplified Process:** It eliminates the need for traditional energy-intensive and polluting steps like coking coal and blast furnaces.
- **Direct Production of Liquid Metal:** MOE directly produces pure liquid metal, which is suitable for continuous casting and other downstream processes.
- **Modular and Scalable:** MOE technology can be implemented in modular, scalable units, allowing for flexibility in production capacity.

Applications:

a. **Steel Production:** MOE has the potential to revolutionize steel production by offering a low-carbon alternative to traditional methods.

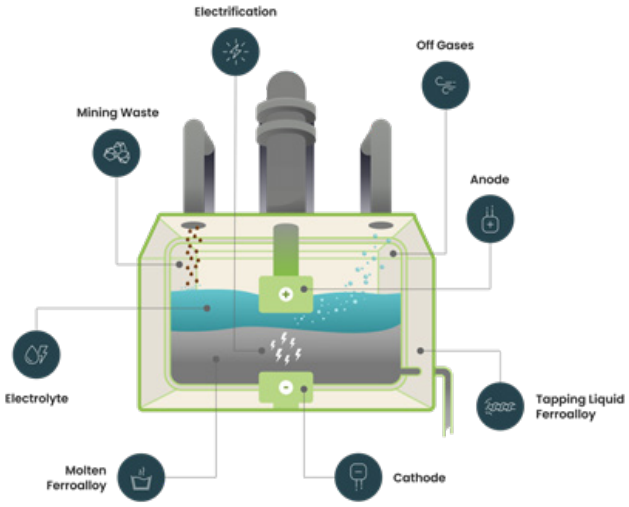


Figure 1. Boston Metal – Molten Oxide Electrolysis (MOE).

b. **Critical Metals Extraction:** MOE can also be used to extract valuable and critical metals from mining waste, providing a sustainable solution for resource recovery.

MOE Cells: MOE technology typically takes place in modular cells, often described as the size of a school bus. Each cell contains an anode and cathode immersed in a liquid electrolyte

QUILL – Rare Earth Metal Recycling

Queen's University Belfast's QUILL (Queen's University Ionic Liquid Laboratories) is developing advanced ionic liquid technologies to recycle rare earth metals.

At QUILL, an innovative ionic liquid-based extractant for the separation of REEs was developed. Combining the expertise in rare-earth separation, coordination chemistry, and ionic liquids, the designed novel functionalized ionic liquid-based extractant, MAIL (Multifunctional Amide Ionic Liquid), is used for the selective liquid-liquid extraction of REEs.Ionic liquids not only have great potential as alternative and more benign solvents but, in addition, the ability to fine-tune their structures enables specific functionality to be imparted. As a result, a more environmentally friendly extractant with superior selectivity was designed. Initial extraction focused on the separation of neodymium/dysprosium metal from 'end-of-life' hard disc drives containing NdFeB magnets. Such metals are essential for magnets in wind turbines and electric vehicles. The process aims to reduce environmental damage and improve the sustainability of metal recovery.

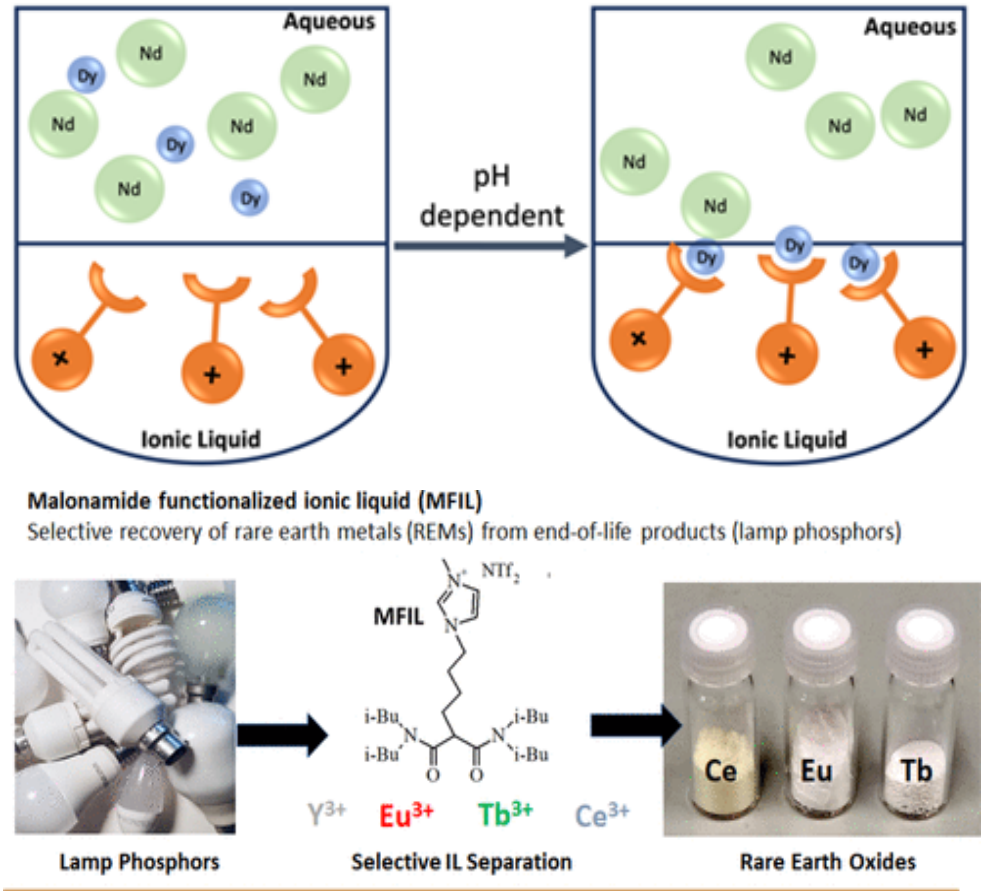


Figure 2. Ionic liquids are composed of ions, both positively and negatively charged, and their unique properties, such as low vapor pressure, high thermal stability, and ability to dissolve a wide range of materials, make them useful in various applications.

2. Commercialization and Market Trends

2.1 Rio Tinto and AMG M&M – Low-Carbon Aluminium in India

Rio Tinto has installed carbon free aluminium smelting cells at its Arvida smelter in Québec, Canada, using the first technology licence issued by the ELYSIS joint venture. This development of the breakthrough ELYSIS™ technology allows Rio Tinto to build expertise in its installation and operation. It's demonstration plant is equipped with ten pots operating at 100 kiloamperes (kA). The plant will be owned by a new joint venture in which Rio Tinto and the Government of Québec, through Investissement Québec, will invest $179 million (CAN$235 million) and $106 million (CAN$140 million) respectively as equity partners, for a total investment of US$285 million (CAN$375 million).This facility uses the same technology that has been successfully demonstrated at the ELYSIS Industrial Research and Development Center in Saguenay—Lac-St-Jean. This pilot operation is a critical step in Rio Tinto's learning journey towards full scale industrialization of the ELYSIS™ technology.The plant will have the capacity to produce up to 2,500 tonnes of commercial quality aluminium per year without direct greenhouse gas emissions, with first production targeted by 2027. It will be located adjacent to the existing Arvida smelter, allowing the use of the current alumina supply and casting facilities.

Rio Tinto has signed a memorandum of understanding with India-based AMG Metals & Materials to explore a low-carbon aluminium project. The initiative may include up to 1 million tonnes per annum of primary aluminium smelting and 2 million tonnes per annum of alumina production, powered by renewable energy sources like wind and solar.

UK's Green Steel Initiative

The UK government is considering converting Scunthorpe steelworks' blast furnaces to use hydrogen for producing 'green steel'. This shift aims to replace traditional carbon-intensive processes with hydrogen-based technologies, supporting net-zero targets .



Figure 3. Rio Tinto Alma smelter for first commercial demo of ELYSIS GHG.

3. Market Leaders in Green and Low-Carbon Metals

En+ Group / Rusal: En+ Group, with a controlling stake in Rusal, is a major producer of aluminium powered by hydroelectricity. This approach results in 80% fewer emissions compared to coal-powered smelters, positioning the company as a leader in "green aluminium" production.

Novelis (Hindalco): Novelis, a subsidiary of Hindalco Industries, is a leading aluminium recycler, processing over 70 billion used beverage cans annually. The company is investing $2.5 billion in a new low-carbon aluminium plant in Alabama, aiming to enhance sustainable aluminium production .

Fortescue: Fortescue has merged its metals and green energy divisions to form a unified entity focused on decarbonizing mining operations. The company is developing the "Infinity Train," a zero-emission electric train that charges itself using gravitational energy .

4. Market Outlook

The demand for green and low-carbon metals is accelerating, driven by the global transition to renewable energy and electric vehicles. Companies investing in sustainable practices and innovative technologies are well-positioned to lead in this evolving market.

12 Month Outlook

Over the next 12 months, the green and low-carbon metals industry is poised for significant advancements, driven by global decarbonization efforts and technological innovations. Here's an overview of anticipated developments:

India: Advancing Green Hydrogen in Steel Production

Under the National Green Hydrogen Mission, the Indian government has allocated ₹455 crore to support pilot projects integrating green hydrogen into steel manufacturing. Three key initiatives include:

- **Matrix Gas and Renewables Ltd**: A 50-ton-per-day plant utilizing 100% hydrogen in the direct reduced iron (DRI) process.
- **Simplex Castings Ltd**: A 40-ton-per-day facility incorporating hydrogen into blast furnaces to reduce coal consumption.
- **Steel Authority of India Ltd (SAIL)**: A large-scale 3,200-ton-per-day plant in Ranchi focusing on hydrogen-based steel production.

These projects aim to validate the technical and economic feasibility of hydrogen-based steelmaking, with commissioning expected within the next three years.
Additionally, JSW Energy plans to commission India's largest commercial-scale green hydrogen plant by late 2025. This facility will supply 3,800 metric tons of green hydrogen annually to JSW Steel, marking a significant step toward industrial decarbonization.

United Kingdom: Transitioning to Sustainable Steelmaking

The UK government is actively exploring the conversion of traditional blast furnaces to hydrogen-based direct reduced iron (DRI) technology at the Scunthorpe steelworks. This initiative aims to reduce carbon emissions and support net-zero targets.
Furthermore, British Steel has received approval to construct an electric arc furnace (EAF) adjacent to the Teesside Beam Mill. This facility, expected to be operational in 2025, will utilize scrap metal, significantly lowering carbon emissions compared to conventional methods.

Australia: Pioneering Green Hydrogen Integration

In South Australia, the Whyalla Hydrogen Facility is under development, featuring a 250 MW electrolyser and 3,600-tonne hydrogen storage capacity. Scheduled for completion in 2025, this facility will supply green hydrogen to the Whyalla

steelworks, enabling the production of green steel.

Global Outlook: Market Dynamics and Leadership

The demand for green and low-carbon metals is accelerating globally, driven by the transition to renewable energy and electric vehicles. Companies investing in sustainable practices and innovative technologies are well-positioned to lead in this evolving market.

5. Adoption, Adaptation, and Transition

When it comes to green and low-carbon metals, the next 12 months will be marked by adoption, adaptation, and transition across multiple layers of the value chain—policy, production, technology, and investment. Here's a breakdown of what that looks like in practice:

Adoption: Scaling Green Practices

1. **Steel and Aluminium Producers Commit to Net-Zero**
   - Major players like Tata Steel, JSW, ArcelorMittal, and Rio Tinto are actively adopting green hydrogen, electric arc furnaces (EAF), and carbon capture technologies.
   - Expect more pilot plants to enter commercial phases, especially in India, Europe, and Australia.
   - Green aluminium smelting using hydro or solar power (e.g., Rusal, Hydro, Vedanta) will gain stronger traction.

2. **Governments as Enablers**
   - Regulatory incentives like carbon credits, tax rebates, and green financing will drive faster adoption.
   - The EU's Carbon Border Adjustment Mechanism (CBAM) coming into full force in 2026 is pushing countries to prepare green supply chains now.

Adaptation: Industry Retooling and Skill Shifts

1. Retrofitting Existing Plants
   - Older blast furnaces are being upgraded to hybrid or hydrogen-based systems.
   - Refineries and recyclers are adapting processes for secondary metals, particularly from electronics and EV batteries.

2. Workforce and Supply Chain Adjustments
   - Traditional mining and metallurgical workers are undergoing reskilling in clean energy processes.
   - Supply chains are being localized to support circular economy models, including traceable, ethical sourcing of metals.

Transition: Structural Shift in Metals Ecosystem

1. Rise of the Circular Economy
   - Expect a surge in **metal recycling**, especially aluminium and rare earths. Companies like **Novelis** and **Acerinox** are leading.
   - Governments are setting recycling targets (e.g., India's Vehicle Scrappage Policy, EU's Green Deal).

2. Market Differentiation: "Green Premium"

- Buyers (especially in EVs, construction, and packaging) will start to **pay a premium for low-carbon metals**, driving segmentation between "green" and "legacy" metals.

3. Investment Flows Shift

- Clean-tech metals (lithium, cobalt, nickel, copper) will attract more green financing than fossil-based mining projects.
- VC and private equity interest is growing in **green metallurgy startups** like Boston Metal, Electra, and Green Lithium.



Figure 4. Adoption, adaptation and transition.