



# National Conference on Critical Metals

Recycling, Innovation, Separation & Processing  
(CRISP-2025)

13 - 15  
October  
2025



## Book of Abstracts

Organized by

Department of Fuel, Minerals & Metallurgical Engineering  
Indian Institute of Technology (ISM) Dhanbad

In Collaboration with





# National Conference on Critical Metals

Recycling, Innovation, Separation & Processing

(CRISP-2025)



Organized by

Department of Fuel, Minerals & Metallurgical Engineering  
Indian Institute of Technology (ISM) Dhanbad



भारतीय प्रौद्योगिकी संस्थान (भारतीय खनि विद्यापीठ) धनबाद



INDIAN INSTITUTE OF TECHNOLOGY (INDIAN SCHOOL OF MINES), DHANBAD



# Messages

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New Delhi - 110 001



**Dr. Vijay Kumar Saraswat**

**Member, NITI Aayog,  
Government of India**

## Message

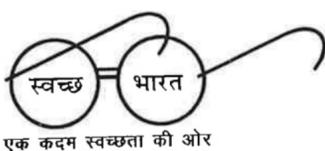
It is my esteemed honor and privilege to extend heartfelt greetings to all the distinguished delegates, eminent scientists, researchers, industry leaders, policymakers, and young innovators attending the National Conference on Critical Metals - CRISP 2025 - here at IIT (ISM) Dhanbad, Jharkhand.

In the backdrop of the accelerating global energy transition and the transformation of industry through digitalization and sustainable technologies, critical minerals and metals have emerged as the lifeblood of modern society. From electric vehicles and renewable energy infrastructure to advanced electronics and aerospace, these resources are indispensable in powering the future. India stands at a pivotal juncture in this monumental shift. Our commitment to achieving net-zero emissions by 2070 and fostering a green, self-reliant economy depends heavily on the secure, sustainable, and innovative management of critical minerals. The National Critical Minerals Mission, complemented by the pioneering research and technological leadership at institutions like IIT (ISM) Dhanbad, exemplifies India's determination to rise from a mineral consumer to a global mineral innovator and supplier.

CRISP 2025 represents a landmark convergence of brilliant minds dedicated to advancing the entire value chain from exploration and extraction to recycling, separation, and processing. It is through such collaborative, multidisciplinary platforms that innovative solutions will flourish, ensuring resource security and environmental stewardship. I encourage all participants to engage deeply, share boldly, and collaborate freely, recognizing that our collective efforts will not only strengthen India's mineral sovereignty but also contribute meaningfully to global sustainability and technological progress.

I congratulate IIT (ISM) Dhanbad now recognized as a Centre of Excellence (CoE) under the National Critical Mineral Mission - for hosting this timely and critical conference. May this event inspire breakthrough innovations and forge lasting partnerships that propel India to the forefront of critical minerals technology and sustainable resource management.

With best wishes for a successful and impactful conference.



(Dr. V.K. Saraswat)



प्रो. सुकुमार मिश्रा  
निदेशक  
Prof. Sukumar Mishra  
FNAE, FNASc, FIET, FIETE, FIE, SMIEEE  
Director

भारतीय प्रौद्योगिकी संस्थान (भारतीय खनि विद्यापीठ) धनबाद  
धनबाद-826004, झारखण्ड, भारत  
Indian Institute of Technology (Indian School of Mines) Dhanbad  
Dhanbad-826004, Jharkhand, India



**Prof. Sukumar Mishra**  
Director  
IIT (ISM), Dhanbad

## Message

It is a privilege for IIT (ISM) Dhanbad to host CRISP 2025, a national conference dedicated to advancing research and innovation in critical metals and minerals that are vital to India's sustainable growth and global technological leadership. As the Director of IIT (ISM) Dhanbad, I warmly welcome all the distinguished researchers, academicians, industry professionals, policymakers, and sustainability experts who have come together for this important event.

CRISP 2025 is held as part of our centenary celebrations, acknowledging 100 years of excellence and continuous evolution from the Indian School of Mines to a premier interdisciplinary technological institute.

The worldwide shift towards sustainable energy and cutting-edge manufacturing depends on the sustainable management of critical metals. India's National Critical Minerals Mission highlights the importance of securing these resources through innovation, responsible mining, recycling, and robust supply chains. As an institute of national importance, we are committed to advancing research and developing solutions that support this national priority, ensuring long-term sustainability and growth. IIT (ISM) Dhanbad is honored to have been designated a Centre of Excellence (CoE) under this mission, serving as a hub for cutting-edge research and technology development in critical minerals. The Department of Fuel, Minerals and Metallurgical Engineering is at the forefront of addressing challenges in mineral processing, extraction, and sustainable lifecycle management aligned with national and global goals.

CRISP 2025 provides a dynamic platform for driving scientific collaboration and industrial innovation in critical metal recycling, separation, and processing technologies. Such partnerships are key to strengthening India's leadership in resource security, sustainable development, and industrial resilience. I urge all participants to actively engage, share insights, and contribute to advancing the future of critical materials science and technology. Let this conference serve as a beacon of knowledge, innovation, and collaboration, empowering India's path toward a greener, more advanced, and self-sufficient future.

I wish the conference great success and thank the organizers of CRISP 2025 who have contributed to making it possible.

(Sukumar Mishra)



भारतीय प्रौद्योगिकी संस्थान (भारतीय खनि विद्यापीठ), धनबाद

धनबाद, झारखण्ड, भारत, पिन - 826004

INDIAN INSTITUTE OF TECHNOLOGY (INDIAN SCHOOL OF MINES), DHANBAD

DHANBAD, JHARKHAND, INDIA, PIN - 826004

(An Institute of National Importance under Ministry of Education, Govt. of India)



**Prof. Dheeraj Kumar**

**Deputy Director  
IIT (ISM), Dhanbad**

## Message

I warmly welcome all distinguished guests and collaborators of the National Conference on Critical Metals: Recycling, Innovation, Separation, and Processing, hosted at the Indian Institute of Technology (Indian School of Mines), Dhanbad.

As we stand at the cusp of a global transition towards cleaner energy, sustainable technologies, and advanced manufacturing, the importance of critical metals and minerals has never been more pronounced. These essential elements underpin the development of electric vehicles, renewable energy systems, aerospace, and digital technologies, making their sustainable management and innovation crucial for economic growth and environmental stewardship.

IIT (ISM) Dhanbad, recognized recently as one of the Centres of Excellence under the National Critical Mineral Mission by the Ministry of Mines, is honoured to lead pioneering research and foster collaborations across academia, industry, and policy domains. The Department of Fuel, Minerals, and Metallurgical Engineering has been at the forefront of advancing knowledge and technology in mineral processing, extractive metallurgy, and sustainable practices, aligning closely with national priorities and global sustainability goals.

CRISP 2025 represents a landmark opportunity to bring together leading scientists, researchers, industry experts, policymakers, and young scholars to share insights, explore innovations, and chart pathways for responsible and efficient critical metal lifecycle management. I encourage all delegates to actively engage, share their expertise, and build meaningful partnerships that will strengthen India's strategic position in critical minerals and propel global efforts towards a sustainable future.

I congratulate the organizing committee and all partners for their dedication to assembling this comprehensive forum. May CRISP 2025 foster fruitful discussions, inspire cutting-edge research, and catalyse impactful collaborations.

Best wishes for a successful and inspiring conference.

**(Dheeraj Kumar)**

V



**Dr. Shatrughan Soren**

**Head of the Department**  
**Dept of FMME, IIT(ISM) Dhanbad**

## **Message**

It is a matter of great pride and privilege for me to extend my warm greetings to all participants of the National Conference on Critical Minerals: Recycling, Innovation, Separation & Processing (CRISP-2025).

The conference comes at a time when critical minerals have become the backbone of emerging technologies such as clean energy, electric mobility, digital infrastructure, and advanced manufacturing. Ensuring their sustainable supply through innovative processing, efficient separation, and effective recycling is not only a scientific challenge but also a strategic necessity for national growth and global competitiveness.

CRISP-2025 provides an excellent platform for researchers, academicians, industry leaders, and policymakers to deliberate on the latest advances and challenges in this vital domain. The exchange of knowledge and ideas here will undoubtedly foster new collaborations, promote indigenous solutions, and strengthen our efforts toward self-reliance and sustainability.

I congratulate the organisers for their commitment to hosting this important event and sincerely wish that CRISP-2025 will inspire innovative research outcomes and pave the way for impactful technological developments in the field of critical minerals.

**(Dr. Shatrughan Soren)**



**Dr. Dhruv Kumar Singh**

**Advisor**

**CRISP-2025**

## **Message**

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Best wishes for a successful and inspiring conference.

*Dhruv Kumar Singh*

**(Dr. Dhruv Kumar Singh)**



*National Conference*

*on*

**CRITICAL METALS: RECYCLING, INNOVATION, SEPARATION, & PROCESSING  
(CRISP – 2025)**

Department of Fuel, Minerals and Metallurgical Engineering  
Indian Institute of Technology (Indian School of Mines) Dhanbad – 826004



**Dr. Aarti Kumari**

**Convenor  
CRISP-2025**

## Message

It is my great pleasure to welcome all delegates, researchers, industry professionals, and students to the national conference on Critical Metals: Recycling, Innovation, Separation and Processing (CRISP 2025). This conference is envisioned as a platform to foster innovation, collaboration, and sustainable solutions in the field of critical minerals. CRISP 2025 is being held at a time when critical minerals are shaping the future of energy systems, industrial development, and technological competitiveness across the globe.

CRISP 2025 is distinctive in its spirit of convergence. Research in critical metals cannot remain confined within individual disciplines. It demands collaboration among geologists, metallurgists, materials scientists, process engineers, environmental specialists, and policymakers. The themes of this conference reflect such breadth, encompassing exploration, beneficiation, processing, separation, recycling, and lifecycle assessment. By drawing these perspectives together, the event provides fertile ground for solutions that are scientifically robust, economically viable, and environmentally sustainable.

This occasion is also significant for IIT (ISM) Dhanbad, which has recently been recognized as a Centre of Excellence under the National Critical Minerals Mission. This designation reflects the institute's leadership in advancing the science and technology of critical metals, while placing on us the responsibility to contribute actively to national and global priorities. CRISP 2025 is one expression of that mandate, serving as a platform for knowledge exchange, innovation, and collaboration at the highest level.

A particularly encouraging feature of this conference is the strong presence of young researchers and students. Their contributions, alongside those of established experts and industry leaders, symbolize the continuity and renewal of scientific inquiry in this vital area. The ideas shared here will not only enrich academic discussion but also guide the development of sustainable technologies and resilient supply chains.

I extend my sincere thanks to all participants, sponsors, and support team for their dedicated efforts. I am confident that CRISP 2025 will inspire meaningful partnerships and contribute significantly to building a secure and sustainable future for critical minerals.

**(Aarti Kumari)**



*National Conference*

*on*

**CRITICAL METALS: RECYCLING, INNOVATION, SEPARATION, & PROCESSING  
(CRISP – 2025)**

Department of Fuel, Minerals and Metallurgical Engineering  
Indian Institute of Technology (Indian School of Mines) Dhanbad – 826004



**Dr. Vishnu Teja Mantripragada**

**Co-Convenor  
CRISP-2025**

## Message

It is a privilege to welcome you to the National Conference on Critical Metals: Recycling, Innovation, Separation, and Processing (CRISP 2025), hosted at IIT (ISM) Dhanbad in its centenary year. This event is both a celebration of the institute's legacy and a forward-looking initiative to address one of the most urgent challenges of our time: securing sustainable pathways for critical minerals.

The global transition to clean energy, digital technologies, and advanced manufacturing depends fundamentally on minerals such as lithium, cobalt, nickel, rare earths, and copper. These resources are essential for renewable energy systems, batteries, magnets, semiconductors, and defence technologies. Ensuring their availability requires much more than exploration. It calls for innovations in processing, recycling, substitution, and the creation of resilient supply chains. CRISP 2025 provides a timely forum to deliberate on these priorities.

A defining feature of this conference is the diversity of its participants. By engaging scientists, industry experts, policymakers, and students in a shared dialogue, the event promotes a holistic approach to critical metals. Scientific insight, industrial experience, and policy direction reinforce one another, leading to solutions that are both practical and future-oriented. For India in particular, building strength in refining, separation, and recycling is vital to transform resource potential into real strategic capability.

The contributions compiled in this volume highlight the ingenuity and commitment of our research community. They illustrate advances in recovery efficiency, reductions in environmental footprint, and innovative approaches to circularity. These outcomes point toward the translation of research into tangible practices. It is my hope that the exchanges during CRISP 2025 will extend beyond the conference and evolve into lasting collaborations.

I express my gratitude to all sponsors and participants for their role in making this event a grand success.

**(Vishnu Teja Mantripragada)**

# Sponsors

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The cover page features a light gray background with a faint, large-scale geometric pattern of overlapping triangles. The design is accented with vibrant blue and dark blue diagonal stripes in the corners and a central graphic element. This central element consists of a dark blue rounded rectangle containing the title, and a large, stylized 'X' shape formed by overlapping light blue and dark blue geometric shapes. Scattered throughout the corners are numerous small, dark blue triangles of varying sizes and orientations.

# Technical Schedule

# Technical Schedule

 Golden Jubilee Lecture Theatre (GJLT), IIT(ISM) Dhanbad

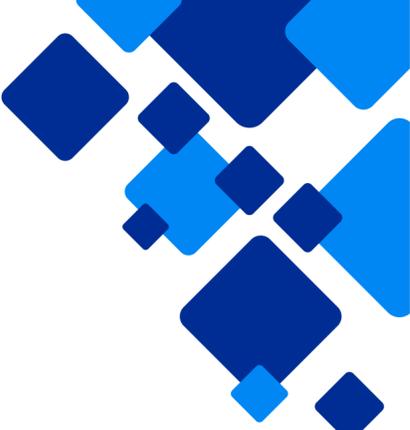
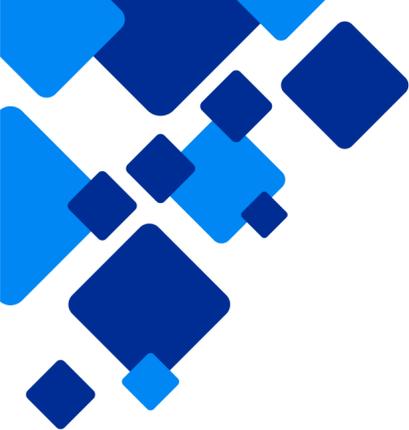
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Day 1: 13<sup>th</sup> October (Monday)  
◇————◇

Time	Event	
08:30 onwards	Registration	
09:30 – 10:45	<b>Inaugural Session</b> <b>Chief Guest: Dr. Vijay Kumar Saraswat, Member, NITI Aayog</b>	
10:45 – 11:15	High Tea	
<b>Session I: Unlocking the potential of Critical Metals for Atmanirbhar Bharat</b> <b>Chair: Dr. D. K. Singh, IIT (ISM) Dhanbad. Co-Chair: Dr. Shatrughan Soren, IIT (ISM) Dhanbad.</b>		
Time	Speaker	Title
11:15 – 11:35	Dr. Deependra Singh, Former CMD, IREL	Evolution of Critical Minerals Era- The REE Experience
11:35 – 11:55	Dr. Raghvendra Tewari, Director, Materials Group, BARC Mumbai	Materials for Gen IV Nuclear Reactors in India
11:55 – 12:15	Dr. Ramanuj Narayan, Director, CSIR-IMMT Bhubaneswar	R&D and Disruptive Multidisciplinary Approach for self-Reliance in Critical Minerals @CSIR-IMMT
12:15 – 12:35	Shri R. Saravanabhavan, Deputy Advisor, NITI Aayog	Overview of the National Critical Mineral Mission and its Prospects
12:35 – 12:55	Dr. B. R. Mishra, Former Head, Rare Earth Processing Plant, IREL Chhatrapur, Odisha	Role of process mineralogy in improving the recovery of heavy minerals from lean grade placer deposit
13:00 – 14:00	Lunch	
<b>Session II: Innovations in Recycling and Metal Extraction</b> <b>Chair: Dr. Anuttam Mishra, IREL. Co-Chair: Dr. Kesavan Ravi, IIT (ISM) Dhanbad.</b>		
Time	Speaker	Title
14:00 – 14:20	Dr. Alok Awasthi, Head, MP & CED, Materials Group, BARC Mumbai	Pyrometallurgy of critical metals -scientific basis for improved practices
14:20 – 14:35	Dr. K. K. Singh, Professor, IIT (BHU)	Recycling of tantalum from waste capacitors: an effort to address the criticality
14:35 – 14:50	Dr. Ebhin Masto, Chief Scientist, CSIR-CIMFR, Dhanbad	Coal as a Potential Raw Material for Critical Minerals
14:50 – 15:05	Dr. Kartikey Kumar Yadav, Scientific Officer, BARC Mumbai	Scalable Next-Generation Hydrometallurgy Process Development for Rare-Earth Extraction from End-of-Life NdFeB Magnets
15:05 – 15:20	Dr. Shivendra Sinha, Principal Scientist, CSIR-NML Jamshedpur	Sustainable recycling of rare earth elements from secondary resources
15:20 – 15:35	Dr. Arunabh Meshram, Assistant Professor, IIT Kanpur	Materials Recycling Pathways: towards circular economy of critical metals
15:35 – 16:15	Poster Session + Tea Break	
<b>Session III: Industry Perspectives on Critical Metals: Innovation, Technology, and Circularity</b> <b>Chair: Dr. Ebhin Masto, CSIR-CIMFR Dhanbad. Co-Chair: Shravan Kumar, IIT (ISM) Dhanbad.</b>		
Time	Speaker	Title
16:15 – 16:30	Dr. Atanu Ranjan Pal, Chief Technology Officer (Process), Tata Steel	Unlocking India's Nickel Potential: Turning Low-Grade Resources into Strategic Advantage
16:30 – 16:45	Dr. Sanjiv Tyagi, CEO, GMDC Science and Research Centre, Gujarat	Innovation & Technologies in Analysis of Critical Metals, Especially REEs
16:45 – 17:00	Shri. B. Srinivasa Rao, GM (Exploration), SCCL	Critical Minerals Exploration and Exploitation for self-sustainable Bharat
17:00 – 17:15	Shri Ajit Singh Choudhary, MD, ELITech Earth Science Pvt. Ltd.	Unlocking the Future of Critical Minerals: Characterisation, Bridging Technology, & Human Capital
17:15 – 17:30	Shri Rajesh Goyal, Founder, Polyprotic Chemicals Pvt Ltd	Indigenously Developed High-Performance Solvent Extractants for Critical Metal Recovery and Refining
17:30 – 17:40	Ms. Mohini Gavhane, Alfa Laval, Pune	Advanced Separation Technologies for Critical Metals - Alfa Laval India Bridging Innovation, Sustainability, and Growing
17:40 – 17:50	Dr. Mohit Gupta, Manager, Process Engineering & Testing Services, Eriez-India, Chennai	Eriez's Novel Separation Technologies for Advancing Critical Minerals Processing
17:50 – 18:00	Shri Vaitheeswaran. J, MD, Sun Technosys Private Limited	Fly ash Beneficiation for High-Value Minerals Recovery
19:00 onwards	Dinner	

# Day 2: 14<sup>th</sup> October (Tuesday)

Time	Event	
08:00 – 09:00	Breakfast	
09:00 – 09:30	Guest of Honor Address by Prof. Chaitanyamoy Ganguly, Founder President, Critical Minerals Association of India	
<b>Session IV: Critical Mineral Resource Development: Challenges and Opportunities</b> Chair: Dr. R. Tewari, BARC. Co-Chair: Dr. Sushanta Sarangi, IIT (ISM) Dhanbad		
Time	Speaker	Title
09:30 – 09:50	Dr. K. Anand Rao, CMD, Uranium Corporation of India Limited (UCL)	Current Status and Trends in Exploitation of a few Critical Metal Ore Deposits Occurring in India
09:50 – 10:10	Shri Anuttam Mishra, Director Technical, IREL	Rare Earths: A catalytic material for advance technologies
10:10 – 10:30	Dr. Arvind Kumar Mishra, Director, CSIR-CIMFR Dhanbad	Critical Mineral Scenario of India
10:30 – 10:50	Dr. Sandip Ghosh Chowdhury, Director, CSIR-NML Jamshedpur	Rare Earth Elements and its Applications
10:50 – 11:10	Shri Mohan Babu Verma, Former Director AMD, Cons (T&I), NSCS	Supply Chain Resilience of Critical Minerals – Indian Perspective
11:10 – 11:30	Tea Break	
<b>Session V: Critical Metals for Emerging Technologies: Separation, Recycling, and Advanced Applications</b> Chair: Dr. Sumantra Bhattacharya, IIT (ISM) Dhanbad. Co-Chair: Dr. Sahendra Singh, IIT (ISM) Dhanbad.		
Time	Speaker	Title
11:30 – 11:45	Dr. T. Sreenivas, Former Head, Mineral Division, BARC Hyderabad	R&D needs for recovery of critical mineral values from mine and process wastes
11:45 – 12:00	Dr. Ranjan Singh, Senior Scientist, DMRL Hyderabad	Thermal Performance Enhancement in Sm-Co and Nd-Fe-B type Rare Earth Permanent Magnets
12:00 – 12:15	Shri Sagar Pandit, Function Head (Technical and R&D), Hindalco, Muri	Value Recovery From Red Mud For Circular Economy
12:15 – 12:30	Dr. Ritesh Ruhela, Scientific Officer, BARC Mumbai	Advances in selective separation of critical metals - A necessity for emerging green technologies
12:30 – 12:45	Dr. Chenna Rao Borra, Assistant Professor, IIT Kharagpur	Synergetic recycling of NdFeB magnets and Li-ion batteries
12:45 – 13:00	Dr. C. Naveen Kumar, Principal Scientist, CSIR-CECRI Karaikudi	Towards Circular Metallurgy: Recovery of Critical Metals from Ores, Wastes, and End-of-Life Products
13:00 – 14:00	Lunch	
<b>Session VI: Advances in Critical Metals Science and Technology</b> Chair: Dr. Kartikey Kumar Yadav, BARC. Co-Chair: Dr. Prabodha Ranjan Sahoo, IIT (ISM) Dhanbad.		
Time	Speaker	Title
14:00 – 14:10	Ms. Atchutanna Vidyadhari, Scientific Officer, BARC Hyderabad	Recovery of Rubidium, Caesium and Potassium from the Leach Residue of Indian Pegmatite Ore
14:10 – 14:20	Mr. Amit Karmakar, Research Associate, CSIR-CIMFR Dhanbad	Exploring Rare Earth Elements in Coal Ash of Singrauli Coalfield, India for Sustainable Resource Recovery
14:20 – 14:30	Mr. Sunil Kumar, Research Analyst, CEEW	Towards indigenous cobalt production through recovery from secondary sources
14:30 – 14:40	Mr. Nishant Kumar Pandey, Sr. Manager, TATA Steel	Hydrometallurgical processing of spent HDS catalyst for recovery of critical metals
14:40 – 14:50	Dr. Ram Karan, Scientific Officer, BARC Hyderabad	Studies on recovery of rare earth elements from coal fly ash of Indian origin using hydrometallurgical techniques
14:50 – 15:00	Mr. Reshu Sinha, Scientific Officer, BARC Hyderabad	Development of process flowsheet for lithium recovery from lepidolite ore of Bihar mica belt
15:00 – 15:10	Mr. Santosh Kumar, PhD Scholar, AcSIR, CIMFR Dhanbad	Evaluation of geochemistry and mineralogy of critical minerals in Indian coal deposits with emphasis on enrichment of REEs
15:10 – 15:20	Dr. Radha Shivaramaiah, Assistant Professor, Atria University	Lithium-Ion Battery Recycling in India: A Perspective
15:20 – 15:30	Dr. Shivaraj Kumar K, Post-Doctoral Researcher, IIT Madras	Debromination of waste printed circuit boards through a zero-discharge solvothermal process
15:30 – 15:40	Dr. Prashant Modi, Assistant Professor, Central Univ. Jharkhand	Coal Washery Rejects: Potential secondary resource for rare earths extraction
15:40 – 15:50	Dr. Pramod Kumar Rajak, Scientist, Wadia Institute of Himalayan Geology, Uttarakhand	Significant occurrences of critical minerals in high ash content Indian coal
15:50 – 16:10	Tea Break	
<b>Panel Discussion on Critical Metals for India's Future: Policy, Technology, and Industry Pathways</b> Coordinator: Dr. D. K. Singh, IIT (ISM) Dhanbad		
<b>Panel Members</b>		
16:10 – 17:10	<b>Prof. Chaitanyamoy Ganguly, Founder President, CMAI</b> <b>Dr. Deependra Singh, Former CMD, IREL.</b> <b>Shri. Saravanabhavan, Deputy Advisor, NITI Aayog</b>	<b>Dr. Dheeraj Kumar, Deputy Director, IIT (ISM) Dhanbad</b> <b>Dr. Sanjiv Tyagi, CEO, GMDC Science and Research Centre, Gujarat</b> <b>Dr. T. Sreenivas, Head, Mineral Division, BARC</b>
17:10 – 18:00	Valedictory Session	
19:00 onwards	Grand Dinner Venue: Scolomin Club, IIT (ISM) Dhanbad	





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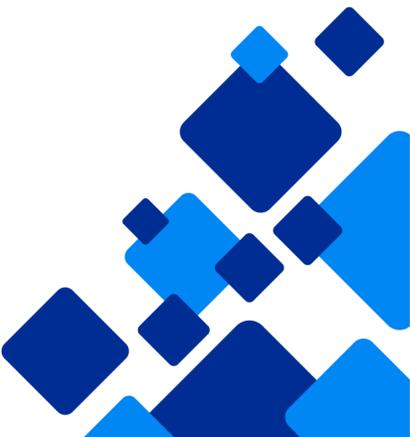
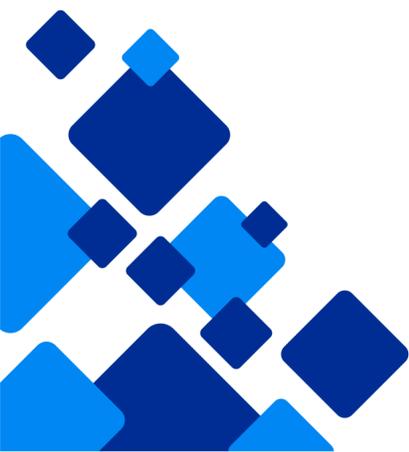
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List of Participants

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# Committees

# National Advisory Committee

Name	Affiliation	Name	Affiliation
Dr. Ramanuj Narayan	CSIR-IMMT	Prof. S. K. Gupta	IIT(ISM) Dhanbad
Dr. D Singh	IREL	Prof. R. M. Bhattacharjee	IIT(ISM) Dhanbad
Dr. Anuttam Mishra	IREL	Prof. Rajini Singh	IIT(ISM) Dhanbad
Dr. K Ramesha	CSIR-CECRI	Prof. Sahendra Singh	IIT(ISM) Dhanbad
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**Parepalli Sooma Surya Darshan**

**Arpit Soni**

**Jagana Venkatesh Kumar**

**Mansha Ram Verma**

# Abstracts

Invited Lectures

# Critical Minerals and Materials for “Energy Security”, “Environmental Protection” and “National Security” and their Life Cycle Management

## Dr. Chaitanyamoy Ganguly

Founder President

Critical Minerals Association of India



## Abstract:

The Government of India has launched the “Atmanirvar Viksit Bharat” mission of making India a self-reliant and a developed nation by its 100<sup>th</sup> anniversary in 1947. The thrust areas of this mission are “Energy Security”, “Environmental Protection”, “Indigenization and Innovation in Materials and Manufacturing Technology”, “National Security” and related “Supply Chain and Life Cycle Management of Critical Minerals and Materials”. Energy is the engine of growth, prosperity and improved quality of life. Sustainable ‘energy security’ will pave the way for food, fuel, electricity and water security, which in turn will contribute to improved quality of life. Decarbonization and mitigation of CO<sub>2</sub>, CH<sub>4</sub> and other greenhouse gas emissions, responsible for global warming and related climate changes, will be essential to meet the UNFCCC (United Nations Framework Convention on Climate Change) target of restricting global warming to  $\leq 1.5^\circ\text{C}$ . The major challenge is the “energy trilemma” and finding the optimal balance between the often conflicting goal of “Energy Security”, “Energy Equity” (affordability and access) and “Environmental Sustainability”. The human development Index (HDI) of the United Nations, based on Per Capita Consumption of Electricity (PCCE) and the Trilemma Index (TI) of the World Energy Council are the usual indicators that will allow policy makers with insights in crafting effective energy strategy. The expert committee of the Ministry of Mines, Government of India, has listed some 30 critical minerals needed as basic raw materials for clean, carbon-free technologies for electric vehicles (EV), wind turbines, solar panels, energy storage batteries, hydrogen fuel cells, permanent magnets, semiconductors and electronic materials. Their focus has been on minerals and materials bearing Si, Li, Co, Ni, graphite, Pt, Cu, rare earth elements (in particular Nd, Sm, Pr & Dy), Ti, Nb, Ta, Mo, W etc). Uranium and thorium, the basic raw materials for nuclear energy and coal are not included in the list. Life cycle management, including recovery and recycling of these critical materials and their progressive indigenization will also contribute towards environmental protection and self-reliance.

India is the third largest producer of electricity in the world with a total installed grid power of some 496 GWe (as of August 31, 2025) but the PCCE is only 1538 kWh, which is way below the world average of some 3670 kWh.

The installed electric power has to be increased at least by a factor of four to five, utilizing both carbon -based and carbon -free primary energy in order to reach a PCCE in the range of 5000 kWh to improve the HDI and TI to the level of developed country . Presently, the installed fossil ( coal , oil & gas) and non -fossil ( hydro ,solar , wind other renewables & nuclear) power are in nearly equal proportion but coal- fired station alone contribute to more than 60% of the generated electricity. Coal will continue to dominate the electricity market at least till 2050 and it will be a challenge to meet the target of net zero emission in India by 2070. CO<sub>2</sub> emission from coal -fired thermal power stations are being reduced by , deployment of high thermal efficiency advanced ultra super-critical boilers operating at 700°C/760°C steam temperatures using advanced Ni –based , high strength superalloys like Inconel 740H and Inconel 617 . Simultaneously , carbon footprint are being minimized by progressively replacing petrol and diesel vehicles by Electric Vehicles (EVs) operating with Lithium Ion Batteries (LIB) and to limited extent Hydrogen Fuel Cells with platinum anode and substituting coal with liquified petroleum gas (LPG) and natural gas (LNG) in industry and for cooking. With the decreasing cost of Silicon Solar Photovoltaic (PV) cells and Lithium Ion Batteries( LIB) , solar and wind have already emerged as the cheapest and sustainable option for electricity generation and green hydrogen production. Solar and wind -solar hybrid roof top power system are the current trends of electricity generation for domestic consumption. There is a need to scale up indigenous production of semiconductor grade Si from quartzite and sand for solar PV, LIB for EVs and energy storage and NdFeB & SmCo permanent magnets , with or without Dy & Pr, from rare-earth deposits ( mainly monazite) for wind turbines and EV engines. The inexpensive Sodium ion Batteries are emerging as an alternative to LIB. Nuclear power, based on utilizing the fission heat energy of U 235, the only fissile material in Nature, has so far been the only carbon - free energy option that has been generating high base -load electricity with very high plant availability factor ( > 85 % ) all over the world since the mid 1960s. Presently, some 440 nuclear power reactors are in operation in 32 countries worldwide with total installed power of nearly 400 GWe, generating some 10 % of global electricity. In addition , 63 reactors of installed power of 66 GWe are under construction. Experts are of the opinion that renewable energy alone will not be adequate to meet the UNFCC climate goal unless nuclear energy is deployed in a bigger way. In India , 26 nuclear power reactors are in operation with total installed power of ~ 8200 MWe, 9 reactors of total installed power of 7300 MWe are under construction and the government of India has announced an ambitious target of some 100 GWe nuclear power by 2047 , including Small Modular Reactors(SMR) . Nuclear reactors should progressively replace the retired fossil fueled power station and utilize the site and the power distribution grid wherever possible. Natural uranium ( 99.3 % fertile U238 + 0.7 % fissile U235) and thorium ( 100 % fertile Th232) are the basic raw material of nuclear fuel , which is a combination of a fissile and fertile material. Long term sustainability of nuclear power will depend on efficient utilization of natural uranium and thorium resources in safe and secured thermal and fast breeder reactors, with reprocessing of spent fuel and multiple recycling of fissile and fertile materials.

Apart from nuclear electricity , Nuclear Marine Propulsion( mainly for strategic application) , Nuclear Hydrogen Initiative (NHI) and Nuclear Desalination (ND) are the emerging non -electric power applications of nuclear energy. Nuclear reactors also produce radioisotopes that are being extensively used in food and agriculture , medicine & healthcare and sterilization of waste. The gamma radiation from radioactive isotopes like Cobalt 60 and Cesium 137 are being extensively used in nuclear agriculture for developing high yield food crop seeds and for post-harvest food irradiation and preservation . Nuclear Fusion energy, based on fusion of deuterium ( H<sub>2</sub> isotope) and tritium ( H<sub>3</sub> isotope), is under development and yet to be commercialized. Tritium does not occur in nature but is produced when Lithium is bombarded with neutron. Thus lithium is used as blanket material for nuclear fusion reactor. Cobalt and lithium are also critical materials for nuclear energy.

The presentation aims to summarize the life cycle management of major critical materials ( C, Si, Li ,Co, Ni , Cr , Mo , Cd, REE, Zr , Na, U & Th etc ) , their indigenization and optimum applications in thermal , solar , wind and nuclear power and EVs with the objective of energy security and environmental protection, highlighting the common processing technology of critical minerals including leaching , solvent extraction , ion exchange, carbo-thermic & metallothermic extraction , fused salt electrolysis and powder metallurgy.

# Evolution of Critical Minerals Era- The REE Experience

**Dr. Deependra Singh**

Former CMD, IREL



## **Abstract:**

The technological evolution in recent decades has led to increased demand for critical minerals and rare earth elements (REEs) across diverse industries with wide-ranging industrial applications, the clean energy sector is one among them. The unique intrinsic properties of these minerals are useful to build technology-empowered society and are often difficult to replace or duplicate by using conventional methods. The occurrence of such minerals may not be in abundance as like bulk minerals, but they have potential to impact the technological development of a society. The most important aspect is to mine economically and sustainably without causing damage to environment including technical feasibility of processing and refining of the minerals for ready use in the industry. The current challenge in India is to develop the supply chain for the critical minerals & rare earths. Other than Rare Earth (RE), exploration of resources for critical minerals is the requirement of today with qualitative aspects of mine. The increased domestic demand for Critical minerals and REE in India is principally driven by the demand for products used in defence and environmental technology. The present manuscript deals with resources, capabilities, exploitation, recovery processes and extraction where a sustainable eco-system for mining, processing, and manufacturing has been taken care.

Key words: Critical minerals, Rare earths, clean energy, defence.

# Materials for Gen IV Nuclear Reactors in India

**Dr. Raghvendra Tewari**

Director, Materials Group,  
BARC Mumbai



## Abstract:

In order to maintain its rapid growth, India must strategize its energy supply. With rising energy demand and increasing dependency on nuclear reactors to cater this demand, there is a growing need for smaller, more efficient reactors that are also intrinsically safe. Hence, development of new class of reactors, called Generation-IV, has been launched. Gen-IV initiative calls for new nuclear energy systems that will significantly improve safety and reliability, sustainability, extended reactor life, proliferation-resistance to name a few. These reactors are expected to operate in the temperature range of 500-1000°C. Therefore, environments proposed for the Gen-IV reactors pose significant challenges to materials selection, as these materials would be exposed to higher temperatures, higher neutron doses, and extremely corrosive or oxidative environments. Typical common temperature ranges may give illusion that a common structural material may serve for various reactors but changing average neutron energy or coolants demand for reactor specific development of materials. The present paper talks about the modifications of already established materials as well as new class of materials which are being developed to meet the stringent requirements.

# R&D and Disruptive Multidisciplinary Approach for Self-Reliance in Critical Minerals @CSIR-IMMT

**Dr. Ramanuj Narayan**

Director,  
CSIR-IMMT Bhubaneswar



## Abstract:

With the announcement of National Critical Mineral Mission (NCMM) by Ministry of Mines, GOI in 2023 as well as our country's journey towards VIKSIT BHARAT in 2047 there has been resurgence in the R&D of Critical Minerals. Many R&D institute and academia has put consistent efforts in the past to build the capacity in this area of research, however, now an integrated, collaborative and multidisciplinary approach is required for the translation of the knowledge generated in sustainable manner since the critical minerals hold the key for self-reliance in clean energy, electronics, defense and industrial sectors and also it will help our country in attaining the broader goals of energy security and net zero emissions. Our concerted efforts are required for the minerals such as lithium, cobalt, rare earth elements, nickel, platinum group of elements from both primary and secondary resources. The collaborative efforts will be able to find solutions in several underlying R&D challenges in critical minerals domains like advanced & sustainable mineral processing for efficient extraction from low-grade ores, use of the secondary & tertiary resources, separation, deep-sea & unconventional mining, application of AI & ML etc. In more than six decades of its journey CSIR-IMMT has contributed in the area of mineral processing & beneficiation, recycling and urban mining, advanced materials & additives development. Environment & sustainability, materials characterization & identification, and hydro, bio electrometallurgy, electronics & devices, pipeline transport etc. and in particular we have built our capacity in almost forty-three elements of periodic table. CSIR in a mission mode involving in various laboratories including CSIR-IMMT is running very ambitious projects on critical minerals viz Mapping & Tapping of Critical Minerals, Lithium Extraction from Primary Resources, Battery to Battery while it is about to start the project SEAs. CSIR-IMMT is working with OMC in PGE processing, with CSIRO on Lithium, Ministry of Earth Sciences on Seabed minerals for the self-reliance in critical minerals. Recently CSIR-IMMT has been selected as one of the Centre of Excellence in Critical minerals with thirty industrial & academic partners by Ministry of Mines. We will try to showcase our expertise & achievements including ongoing activities in critical minerals with emphasis on underlying science & technology during the presentation & deliberation thereof. The adoption & adaption of Disruptive Multidisciplinary approach holds the promise for Critical Minerals.

# Overview of the National Critical Mineral Mission and its Prospects

**Shri R. Saravanabhavan**

Deputy Advisor,  
NITI Aayog



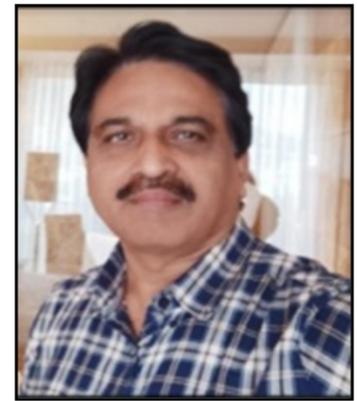
## **Abstract:**

India has been rated as a nation well endowed in natural mineral resources. India is ranked 4th amongst the mineral producer countries, next to China, United States and Russia, on the basis of volume of production. It is an extremely important sector and contributes significantly to the Gross Domestic Product. Government of India has brought in policy reforms in the mineral sector to ensure security in minerals, including critical minerals, through enhanced domestic capacity, leverage multilateral and bilateral cooperation for resilient mineral supply chain, enhancing the participation of private sector in mineral exploration, low carbon mining and recycling of minerals/metal extraction by bringing in transparency in the sector. Therefore, with the aforesaid scenario, Government of India has rightly positioned itself in implementing the right policies in the mining sector to achieve the desired goals as these policies require effective monitoring mechanism & further alterations to promote domestic manufacturing in order to facilitate the long standing target of ensuring a higher GDP contribution in the manufacturing sector. The recent announcement of the National Critical Mineral Mission (NCMM) by the Cabinet in January, 2025 was a well structured exercise for creating a critical mineral ecosystem aligning with India's strategic and economic interests, with participation from Ministry of Mines, private and public stakeholders including various Ministries / Departments and State Governments. The aim of this mission is to ensure a resilient supply chain, promote technological innovation in critical mineral value chain and ensure self-sufficiency in meeting industrial demands, protecting the supply chain against geopolitical risks and market fluctuations, etc. The National Critical Mineral Mission gives long overdue recognition to mineral security as an important issue with strategic as well as economic significance, and seeks long term mineral security for the nation through enhanced exploration and development at home and acquisitions of overseas mineral assets. China had a strategy on critical minerals since 2005 thereby in spite of having limited resources of critical minerals such as cobalt and nickel, it moved forward to other potential countries for acquiring mining assets and mining companies in geographies such as Democratic Republic of Congo, Australia, Indonesia, Chile, Argentina & Peru.

# Role of process mineralogy in improving the recovery of heavy minerals from lean grade placer deposit

**Dr. B. R. Mishra**

Former Head, Rare Earth Processing Plant,  
IREL Chhatrapur, Odisha



## Abstract:

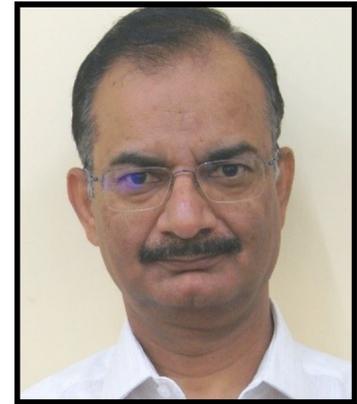
Placer deposits are formed through natural processes such as weathering and the action of water, wind, or gravity, leading to the accumulation of heavy, dense, and weather-resistant minerals like ilmenite, rutile, zircon, sillimanite, garnet, and rare earth-bearing minerals. These deposits are vital sources of critical materials used in advanced technologies including electronics, robotics, and biotechnology. With rising industrial demand, especially in electronics, ceramics, and construction, the focus has shifted toward exploiting lean or off-grade deposits due to the depletion of high-grade resources. The deposit studied in this work contains only 3–4% total heavy minerals, predominantly low-value minerals such as garnet, sillimanite, and pyroxenes, while rare earth-bearing minerals are present at less than 0.05%. This mineralogical composition presents significant challenges for efficient recovery and beneficiation. The objective of this study is to characterize the lean placer deposit and develop an optimized process flow sheet to enhance the recovery of economically valuable minerals like zircon and rare earth-bearing minerals. A comprehensive mineralogical analysis is integrated with beneficiation techniques including gravity concentration, magnetic separation, high-tension electrostatics, and flotation. Pilot-scale trials, guided by mineralogical insights, validate the proposed improvements in recovery. This presentation emphasizes the importance of process mineralogy in designing effective beneficiation strategies for low-grade placer deposits.

**Keywords:** Process mineralogy, lean placer deposit, rare earth recovery, heavy minerals, beneficiation efficiency, garnet, sillimanite, pyroxenes.

# Pyrometallurgy of critical metals - scientific basis for improved practices

**Dr. Alok Awasthi**

Head, MP & CED, Materials Group,  
BARC Mumbai



## Abstract:

Critical metals are not available in nature in extractable concentrations. Even after these are concentrated, production of most of such metals is difficult as these are usually highly reactive and require high temperatures at the same time. Although the extraction of ferrous and common non-ferrous metals has fully matured, many of the practices for extraction of critical metals are based on just thumb rules. Purity issues are fairly common, which limit the applications of extracted metals. The science of pyrometallurgy has not been studied much. The theoretical basis of extraction and refining of such metals would be discussed in the talk. Extraction process may consist of many sequential chemical reactions. Study of such reactions may guide about suitable interventions that would make the overall process more efficient. Consistency of theoretical understanding and practical observations should be brought out for developing a process with minimal experimentations. The talk would also include case studies from the author's experience in extraction of niobium, tantalum and rare earth metals.

# Recycling of tantalum from waste capacitors: an effort to address the criticality

**Dr. Kamalesh Kumar Singh**

Professor, IIT (BHU)



## Abstract:

Capacitors are an integral part of any electronic product. Amongst various capacitors the tantalum capacitors are widely used in electronic devices due to their exceptional capacitance per unit volume. Consequently, over 40% of global tantalum production is consumed by the electronics industry, cementing its status as a critical metal. However, the consistent supply of tantalum faces significant vulnerability stemming from limited natural resources and geopolitical instability. To mitigate supply chain pressures, recycling tantalum from end-of-life capacitors presents a viable strategy for closing the material life cycle loop. This paper reports a highly efficient two-stage leaching process achieving almost 99% tantalum recovery from electronic capacitor scrap. The process commences with pre-treatment involving hammer milling and physical separation to generate silica-free fine particles optimized for subsequent acid leaching. After pre-treatment of waste capacitors, the milled scrap is sent for multi-stage leaching. In the first stage of leaching, dilute hydrochloric acid (3M) at 30-50°C selectively dissolves manganese, nickel, and iron impurities, leaving behind tantalum and the majority of silver in the solid residue. Further, in the second stage of leaching nitric acid with 3 molar concentration is employed at 50°C to leach the remaining silver and minor impurities which is able to isolate tantalum in the residue, further. The final residue comprises 99.9% pure tantalum, which is ready to be sold in the market.

Keywords: Recycling, Tantalum, Capacitors, Leaching .

# Coal as a Potential Raw Material for Critical Minerals

**Dr. Ebhin Masto**

Chief Scientist,  
CSIR-CIMFR, Dhanbad



## Abstract:

India has a wide variety of coal reserves, mainly consisting of bituminous and lignite coal, with an annual production of around 800 million tons. Coal and its associated rocks may contain important critical elements. These elements can be extracted from various sources, including coal mine overburden rocks, shale, and washery rejects, which often include valuable minerals. The combustion of coal in thermal power plants generates approximately 300 million tons of ash per year, with additional large amounts stored in legacy ash ponds. This coal ash represents a significant source of critical minerals, such as gallium (Ga) and rare earth elements (REEs). Studies show that concentrations of REEs in bituminous coal ash range from 400 to 500 mg/kg, while lignite ash can have REE levels up to 3000 mg/kg, influenced by the combustion technology used. Additionally, coal overburden rocks and shales often contain REE concentrations exceeding 1000 mg/kg. Despite the potential for extracting these critical elements from fly ash and coal mine waste, current activities are largely limited to laboratory-scale processes. Collaborative projects, such as the CSIR-IMMT's pilot facility with NALCO for REE extraction from bituminous coal ash and a recent agreement between Neyveli Lignite Corporation and BARC for lignite ash, are being developed to tackle this challenge. The Government of India supports the extraction of critical minerals from mine overburden and fly ash through its National Critical Mineral Mission, promoting policies and funding for research to establish a circular economy based on these secondary resources.

**Keywords:** Critical Minerals, Coal Ash, Rare Earth Elements (REEs), Sustainable Resource Extraction.

# Scalable Next-Generation Hydrometallurgy Process Development for Rare-Earth Extraction from End-of-Life NdFeB Magnets

**Dr. Kartikey Kumar Yadav**

Scientific Officer,  
BARC Mumbai



## Abstract:

Rare earth elements (REEs), notably neodymium (Nd), praseodymium (Pr), dysprosium (Dy), and terbium (Tb), are critical to advanced technologies, particularly NdFeB permanent magnets, which exhibit magnetic strength significantly surpassing ferrite magnets. These magnets, containing approximately 25–30% Nd alongside Pr, Tb, and Dy, are integral to computer hard disk drives (HDDs), electric vehicle motors, wind turbines, and smartphones. The disposal of end-of-life HDDs represents a valuable secondary source of REEs, addressing the scarcity of primary resources and the environmental challenges of electronic waste (e-waste). To meet these demands, an energy-efficient, cost-effective, and environmentally sustainable hydrometallurgical process was developed for recovering high-purity REEs from NdFeB magnet scrap. The process begins with dismantling HDDs to extract NdFeB magnets, followed by thermal demagnetization at 350 °C to facilitate subsequent processing. The demagnetized material is crushed and leached in mineral acids (sulfuric, hydrochloric, or nitric) under optimized conditions of temperature, acid concentration, and particle size. Selective precipitation as double sulfates effectively removes iron impurities, followed by conversion to rare earth hydroxides or oxalates, achieving purities exceeding 98% and recovery efficiencies above 85%. Innovative separation technologies enhance the process's efficiency and sustainability. Polyethersulfone (PES)-based composite beads, encapsulating organic extractants (e.g., D2EHPA, PC88A, TEHDGA) via a phase inversion method, were developed to minimize hazardous organic diluents. Optimized with additives like polyvinyl alcohol and multiwall carbon nanotubes, these beads exhibit tailored porosity, excellent stability, and reusability across 50 extraction-stripping cycles, validated in continuous column mode operations at scales from 20 g to 1 kg per batch [1,2]. Parametric studies on aqueous phase acidity, metal ion concentration, competitive ions, and temperature confirmed robust REE sorption from industrial effluents, including fertilizer-grade phosphoric acid. This integrated process flow sheet, achieving >95% REE recovery and >99% purity at kilogram scale, aligns with circular economy principles, offering a scalable, eco-friendly solution to resource scarcity and e-waste management.

# Sustainable recycling of rare earth elements from secondary resources

**Dr. Shivendra Sinha**

Principal Scientist,  
CSIR-NML Jamshedpur



## Abstract:

NdFeB magnets are the strongest permanent magnets available, valued for their superior magnetic strength that enables reduction in product size and weight. They are extensively used in electric vehicles, renewable energy systems, hard disk drives, sensors, switches, motors, generators, and transducers. Market studies indicate that motors and generators account for the largest share of NdFeB consumption (34%), largely driven by demand from electric vehicles and wind turbines. However, the growing reliance on NdFeB magnets and the limited availability of neodymium, praseodymium, and dysprosium create significant supply chain risks. To ensure sustainable growth, alternative strategies and resource options are being pursued. Waste NdFeB magnets are increasingly recognized as a valuable secondary source of rare earth elements (REEs). It is estimated that around 300,000 tons of REEs are currently stockpiled globally in the form of magnets, with waste volumes expected to increase from diverse applications. This study reviews the main recycling approaches—direct recycling, pyrometallurgical, hydrometallurgical, and electrometallurgical processes—developed for recovering REEs from waste NdFeB magnets. The success of recycling depends on the type of waste (scrap, sludge, or spent magnets) and its contamination level. Direct recycling is suitable only for non-oxidized magnets, while pyrometallurgical routes such as liquid metal and molten salt extraction recover rare earths at high temperatures as alloys or compounds requiring further purification. These methods often face trade-offs between yield and purity. Hydrometallurgical processing, though effective, is hindered by high chemical consumption, and selective leaching with minimal acid remains challenging. Although numerous methods have been developed, none are yet robust, eco-friendly, and efficient at an industrial scale. Considerable scope exists for new technologies capable of selective extraction and large-scale recovery of REEs. The paper also outlines future directions for sustainable recycling strategies to strengthen the supply chain of these critical raw materials.

# Materials Recycling Pathways: towards circular economy of critical metals

**Dr. Arunabh Meshram**

Assistant Professor, IIT Kanpur



## Abstract:

Of late, the resource utilization has increased manifold in various sectors including metallurgical and electronic industries. A similar surge of advances in technology is evident to judiciously utilize natural and waste streams for material recovery, especially in the area of critical metals. With a plethora of key properties and specialized uses in strategic, telecommunication and electronic applications, critical metals hold a significant role in circular economy. This work highlights how materials recycling opens multiple pathways towards achieving circular economy and how deeply rooted is materials recycling in modern-day scenarios. Some examples on recovery of Li, REE etc. will describe the material flow, the energy dependence and overall impact vis-à-vis unorganized recycling methods. These insights describe why materials recycling operations are fundamental to achieving circular economy.

Keywords: Materials Recycling, Recovery, Critical minerals, Circular Economy.

# Innovation & Technologies in Analysis of Critical Metals, Especially REEs

**Dr. Sanjiv Tyagi**

CEO, GMDC Science and  
Research Centre, Gujarat



## Abstract:

Of late, the resource utilization has increased manifold in various sectors including metallurgical and electronic industries. A similar surge of advances in technology is evident to judiciously utilize natural and waste streams for material recovery, especially in the area of critical metals. With a plethora of key properties and specialized uses in strategic, telecommunication and electronic applications, critical metals hold a significant role in circular economy. This work highlights how materials recycling opens multiple pathways towards achieving circular economy and how deeply rooted is materials recycling in modern-day scenarios. Some examples on recovery of Li, REE etc. will describe the material flow, the energy dependence and overall impact vis-à-vis unorganized recycling methods. These insights describe why materials recycling operations are fundamental to achieving circular economy.

Keywords: Materials Recycling, Recovery, Critical minerals, Circular Economy.

# Critical Minerals Exploration and Exploitation for self-sustainable Bharat

**Shri. B. Srinivasa Rao**

GM (Exploration), SCCL



## Abstract:

Mineral industries are the backbone of a developing nation like India, playing a vital role in driving economic growth and sustainable development. In pursuit of realizing the vision of Atma Nirbhar Bharat, certain minerals with strategic importance, such as Rare Earth Elements (REEs), assume a crucial position. REEs are essential components in various cutting-edge technologies including Clean energy solutions, such as wind turbines, solar panels, Electronics including smartphones, laptops, and other devices Defense applications, such as missile guidance systems and advanced ceramics. The global supply of REEs is limited and geopolitically sensitive, underscoring the need for exploration and exploitation of these minerals to ensure a greener and more sustainable future. In this context, domestic, underutilized sources like coal, fly ash, bottom ash, shale, clay, and sandstones offer significant potential. Notably, REEs can be produced as valuable by-products from existing coal mining activities. Coal-related materials and clays often exhibit slight enrichment of valuable Heavy Rare Earth Elements (HREEs) and Critical Rare Earth Elements (CREEs). Moreover, these materials tend to have lower concentrations of radionuclides like uranium (U) and thorium (Th) compared to traditional REE ore deposits. Recovering REEs from coal materials can help mitigate or eliminate legacy environmental issues associated with red mud and coal waste. However, the main challenge in extracting REEs from coal-related materials lies in their relatively lower total REE concentrations (100-400 ppm) compared to conventional ores (1000-10000 ppm). To overcome this challenge, there is an urgent need for Cost-effective extraction technologies, Environmentally benign processing methods, Highly efficient separation techniques. By developing and deploying such technologies, we can unlock the economic potential of India's domestic reserves and take a significant step towards achieving sustainable development and Atma Nirbhar Bharat. As part of its strategic objectives, the SCCL Exploration Division launched an extensive sampling campaign across various opencast mines and the Singareni Thermal Power Plant (STPP). Numerous samples were collected and subjected to detailed analysis at multiple laboratories, revealing the presence of Rare Earth Elements (REEs) in concentrations ranging from 200 to 400 parts per million (ppm).

To improve REE concentration, SCCL partnered with a research institute to carry out Physical Beneficiation and Chemical Leaching trials. These trials yielded promising results, achieving up to a tenfold increase in REE concentration and a recovery rate upto 75%. The findings highlight strong potential for developing an effective process to extract REEs from SCCL's coal-based materials, opening avenues for further research and technological development.

# Unlocking the Future of Critical Minerals: Characterisation, Bridging Technology, & Human Capital

**Shri Ajit Singh Choudhary**

MD, ELITech Earth Science Pvt. Ltd.



## Abstract:

The increasing demand for critical and rare earth minerals is driven by their essential role in technological advancement in renewable energy, electronics, telecommunications, space programs, defence systems and high-grade steel products. These minerals, though sometimes plentiful in the Earth's crust, are often dispersed, making their extraction and processing technoeconomically challenging. This has led to a global scenario where a few nations dominate the refining and processing capacities, with the top few refining nations controlling approximately 86% of the market for key minerals like copper, lithium, nickel, cobalt, graphite, etc., while China alone accounting for 90% of processing of the Rare Earth Elements (REE). This concentration has created vulnerable supply chain risks, especially in the daily changing geopolitical scenario. Future projections indicate that overall mineral demand is expected to triple by 2040, with clean energy technologies quadrupling their demand for these minerals. For instance, by 2040, critical minerals are projected to account for a significant portion of the demand for clean energy applications, including over 40% for copper and REE, and nearly 90% for lithium. India has identified 30 critical minerals essential for its economy and national security, recognizing their importance for technologies like electric vehicles, advanced battery systems, space & defence programs, high-end niche steel products, etc. However, India's current reliance on imports, which is over 85% for key minerals like lithium, cobalt, and nickel, leads to significant supply chain vulnerabilities. To address this, the Indian government is actively pursuing strategies to ensure a secure and sustainable supply through domestic exploration, international partnerships & investments and recycling initiatives. To unlock this future, a multi-faceted approach is necessary, focussing on technology, policy, and human capital, especially, skill-set. Advanced technologies such as Hyperspectral Imaging and Drones are crucial for rapid exploration and discovery, while innovative processing methods, like advanced hydrometallurgy and urban mining, can enable sustainable extraction and recycling from e-waste. The article highlights the need for integrated solutions across the entire value chain, from surveying and geology to extraction and processing of REE as well as critical minerals & metals.

Specific primary processing methods for minerals like lithium, cobalt, and REE are outlined, noting their advantages and disadvantages, such as the energy-intensive nature of some pyro metallurgical methods versus the environmental benefits of bio-hydrometallurgy. Ultimately, bridging technologies to bring together R&Ds into commercial scale is important. Focus on human capital is also paramount, which calls for updating university curricula in geology and metallurgy, thereby creating a skilled workforce across the entire value chain to reduce dependence on foreign expertise. This integrated approach is crucial for India to achieve economic self-reliance and secure its national interests in the face of growing global demand for critical minerals/metals and rare earth elements.

Keywords: critical, rare earth minerals, dominate, refining, processing, supply chain, vulnerability, economy, clean energy, security, unlock, bridging technologies, policy, human capital, economic self-reliance.

# Indigenously Developed High-Performance Solvent Extractants for Critical Metal Recovery and Refining

**Shri Rajesh Goyal**

Founder, Polyprotic Chemicals Pvt Ltd



## Abstract:

The global demand for sustainable and secure supply chains of critical and strategic metals such as cobalt, nickel, copper, uranium, and rare earth elements has accelerated the need for efficient separation technologies. PolyProtic Chemicals Pvt Ltd has indigenously developed a suite of advanced solvent extractants under the MetScav® product line, engineered to deliver high selectivity, efficiency, and phase stability in hydrometallurgical circuits. The flagship products, MetScav® Ultra and MetScav® 90 (bis(2,4,4-trimethylpentyl)phosphinic acid), provide superior cobalt–nickel separation performance, enabling efficient cobalt recovery from battery recycling and primary refining operations. Complementary offerings such as MetScav® D2EHPA (for zinc and manganese extraction) and MetScav® TBP (for uranium and rare earth separations) expand the portfolio across the critical minerals value chain. These solutions are the result of years of R&D-led process innovation and manufacturing expertise in organophosphorus chemistry, aligning with India's National Critical Mineral Mission and the global push towards circular economy and resource independence. By offering reliable, high-purity, and cost-effective alternatives to imported extractants, PolyProtic aims to empower domestic industries and strengthen global partnerships in battery recycling, mining, and advanced material production.

Keywords: Metal recycling, solvent extractants, MetScav, Battery recycling, Hydrometallurgy.

# Advanced Separation Technologies for Critical Metals - Alfa Laval India Bridging Innovation, Sustainability, and Growing Market Needs

**Ms. Mohini Gavande**

Alfa Laval, Pune



## Abstract:

The accelerating adoption of electric vehicles, renewable energy, and digital technologies is driving exponential demand for critical metals such as lithium, cobalt, nickel, and rare earth elements. While India is progressing toward self-reliance through the National Critical Minerals Mission, challenges remain in ensuring sustainable supply and reducing dependence on imports. Recycling of end-of-life batteries, e-waste, and industrial residues has emerged as a key pathway for securing these resources. Alfa Laval, with over 140 years of global leadership in separation and heat transfer technologies, provides innovative solutions for sustainable recovery of critical metals. Advanced High-Speed Decanters, Disc Stack Centrifuges, Evaporators - Zero Liquid Discharge system, and Plate Heat Exchangers enable efficient processing of black mass, solvent extraction streams, and metallurgical intermediates. These technologies enhance metal recovery yields, reduce energy consumption, minimize effluent generation, and support circular economy goals. Alfa Laval will present practical insights into the role of separation technologies across hydrometallurgical, pyrometallurgical and mechanical recycling processes. Case studies will highlight how Alfa Laval solutions are applied in conventional mining and metals and now extended to battery recycling and critical metal recovery. The presentation will also explore opportunities for technology localization, digital integration, and partnerships to align with India's Battery Waste Management Rules (BWMR 2025) and Extended Producer Responsibility (EPR) framework. By enabling scalable and environmentally sound recycling, Alfa Laval contributes to India's journey toward resilient supply chains, resource security, and sustainable industrial growth.

# Eriez's Novel Separation Technologies for Advancing Critical Minerals Processing

**Dr. Mohit Gupta**

Manager, Eriez-India, Chennai.

## **Abstract:**

The Indian mining sector holds a diverse portfolio of critical minerals that can meet the increasing domestic demand. However, it faces significant challenges, including the depletion of high-grade ore reserves, mounting environmental and regulatory pressures, and the growing necessity to process low-grade, complex ore bodies and secondary resources. Traditional beneficiation methods, constrained by inherent design limitations, often fail to deliver the desired results. To address these gaps, this communication highlights the integration of Eriez's state-of-the-art magnetic separation and flotation technologies. Founded in 1942 in the USA, Eriez has consistently invested in the development of advanced solutions for mineral beneficiation, aimed at maximizing recovery and improving plant performance to meet the future needs of industries demanding high-purity products. Eriez offers a comprehensive range of low, medium, and high-intensity magnetic separators—designed for both wet (slurry-based) and dry processing applications, in batch or continuous modes. Complementing these are advanced gravity separation systems and coarse-to-fine particle flotation technologies, enabling a complete flowsheet approach for both metallic and non-metallic ore processing. In this presentation, we will showcase Eriez's extensive equipment portfolio along with global case studies that demonstrate our strengths and proven achievements to advance sustainable processing of critical minerals.

# Fly ash Beneficiation for High-Value Minerals Recovery

**Shri Vaitheeswaran J**

MD, Sun Technosys Private Limited

## **Abstract:**

Background:

Unscientific disposal of fly ash adversely affects local ecosystems due to heavy metal pollution caused by erosion and leachate generation. In addition to occupying vast areas of land, fly ash, if not managed properly, can become airborne due to its lightweight nature. Dumped fly ash contaminates surface water, groundwater, soils, and vegetation through the mobilization of hazardous metals. To reduce the environmental impact of fly ash and minimize the land required for its disposal, the Ministry of Environment and Forests has issued several notifications mandating the 100% utilization of fly ash. Fly ash contains valuable minerals; its major constituents include titanium oxide ( $\text{TiO}_2$ ) and iron oxide ( $\text{Fe}_2\text{O}_2$ ), while minor elements include chromium, cobalt, manganese, nickel, vanadium, lanthanum, cerium, praseodymium, neodymium, yttrium, palladium, and others. These minerals can be recovered before fly ash is used for landfilling or other civil applications.

Methodology:

We have developed a proprietary, cost-effective technology for large-scale segregation and beneficiation of fly ash, targeting both Class F and Class C grades. This innovative process achieves significant volume reduction through mechanical separation while recovering high-value minerals and rare earth mineral concentrates.

Findings:

Fly ash beneficiation was carried out to enrich heavy rare earth element (HREE) and light rare earth element (LREE) concentrates using gravity separation, density separation, magnetic separation, and electrostatic separation techniques.

From fly ash, we successfully recovered 1.1% HREE concentrate and 0.53% LREE concentrate. The recovered materials include titanium oxide ( $\text{TiO}_2$ ) and iron oxide ( $\text{Fe}_2\text{O}_2$ ) as major constituents, along with minor elements such as chromium (107 ppm), cobalt (10.42 ppm),

manganese (444 ppm), nickel (24 ppm), vanadium (120 ppm), lanthanum (110.83 ppm), cerium (251.15 ppm), praseodymium (29.58 ppm), neodymium (82.54 ppm), yttrium (64.58 ppm), palladium (2.32 ppm), iridium (0.94 ppm), and platinum (0.495 ppm).

Conclusion: Fly ash beneficiation enables the recovery of valuable minerals, with  $\text{TiO}_2$  and  $\text{Fe}_2\text{O}_3$  as major outputs and several rare earth elements as minor constituents. These concentrates can undergo further processing to extract individual minerals for industrial applications before the residual ash is used for landfilling or construction purposes. The recovery of rare earth elements, in particular, can contribute to meeting the growing demand for magnets and other advanced technologies, although on a modest scale.

# Current Status and Trends in Exploitation of a few Critical Metal Ore Deposits Occurring in India

**Dr. Kacham Anand Rao**

CMD, Uranium Corporation of India  
Limited (UCIL)



## Abstract:

Critical metals are essential raw materials that play a pivotal role in modern technologies, clean energy systems, and advanced materials. Their unique physical and chemical properties make them indispensable in the manufacture of renewable energy systems, electric vehicles, aerospace, defense, and digital infrastructure. However, the limited availability of economically viable deposits, coupled with the concentration of production in a few geographic regions, has raised significant concerns regarding supply security and geopolitical vulnerability of critical metals. With the growing global demand and India's commitment to achieve 'Net Zero' emissions by 2070 aided by expansion of nuclear power capacity to 100 GW by 2047, it is imperative to accelerate the exploration and sustainable exploitation of indigenous resources of uranium and other critical minerals. A truly sustainable energy cycle integrates production, storage, and consumption in an environmentally responsible manner. In this context, uranium for nuclear power generation, lithium for energy-storage batteries, and Rare Earth Elements (REEs) for renewable energy technologies - such as electrical vehicles and wind turbines are of critical importance. At present, India operates three uranium mills with a combined annual output of about 550 tons of  $U_3O_8$ , which is about 1% of global uranium production. The country also produces around 3,000 tons of REO - less than 1% of world production - from monazite-based placer deposits rich in light REEs. Currently, India does not have any operating production facility for lithium. To achieve the 'Net Zero' targets, production of these critical metals must be scaled up significantly through a combination of expanded domestic recovery and strategically managed imports. In line with national interest, process flowsheet development has been undertaken at Mineral Processing Division of BARC for the exploitation of newly explored uranium, lithium, and REE resources. The processing of Indian uranium ores is particularly challenging due to their low grades and complex mineralogy. The process schemes developed include hybrid process schemes with extensive reagent recycling to improve economic viability. Pioneering studies on hard-rock deposits enriched in heavy REEs and low thorium content, have been conducted, leading to the development of process flowsheets that employ low acid dosages and cost-effective reagents such as sodium sulfate.

Comprehensive flowsheets have also been developed for resource valorization by recovering associated critical metals such as niobium, zirconium, hafnium, and magnesium as by-products. In pursuit of environmentally sustainable extraction technologies, greener solvents such as including deep eutectic solvents (DESs) and organic acids have been evaluated for use in the recovery of REEs from hard-rock deposits and secondary resources such as coal fly ash. A process flowsheet has been developed and tested at bench scale for indigenous resources of Li, with varying Li<sub>2</sub>O grades. This paper presents the current status and recent advancements in the exploitation of critical metals in India, with particular emphasis on uranium, REEs, and lithium.

# Rare Earths: A catalytic material for advance technologies

**Shri Anuttam Mishra**

Director Technical, IREL



## Abstract:

Rare Earth Elements (REEs) are a group of 17 chemically similar elements that play a critical role in modern technology. Despite their name, they are relatively abundant but challenging to extract economically. These elements are indispensable in the production of advanced devices and systems due to their unique magnetic, luminescent, and electrochemical and catalytic properties. They are widely used in smartphones, digital cameras, computer hard drives, and flat-screen displays. REE like neodymium and dysprosium are essential for manufacturing powerful magnets used in electric vehicles, wind turbines, and robotics. Additionally, they are crucial in LEDs, lasers, and fiber optics, as well as in military applications such as precision-guided weapons and radar systems. Their importance stems from their ability to enhance performance, efficiency, and miniaturization of devices, making them vital for technological advancement and the transition to sustainable energy solutions. However, their extraction and processing pose environmental and geopolitical challenges, emphasizing the need for sustainable practices and recycling initiatives. IREL (India) Limited, a Public Sector Undertaking under the Department of Atomic Energy, is critically committed to the processing of RE bearing mineral to produce REE, a cornerstone of modern technology and India's self-reliance in critical materials. As the sole entity in India with the mandate to produce REE, IREL addresses the dual challenge of meeting the escalating domestic demand and reducing import dependency, particularly in the face of geopolitical vulnerabilities in global supply chains. This talk will outline the IREL's strategic role, technical capabilities, and future outlook in establishing a robust indigenous REE ecosystem. IREL utilizes advanced processing techniques, including solvent extraction technology at its plants in Odisha and Kerala to produce high-purity separated RE oxides. The company's efforts are aligned with national priorities under initiatives like the National Critical Mineral Mission to secure the supply of these "vitamins of modern industry" for applications in green energy, electronics, and defense. Despite challenges such as limited downstream industries, IREL is expanding its production capacities and fostering the growth of the domestic value chain by supplying raw materials to upcoming magnet manufacturers. By leveraging its R&D and operational strengths, IREL is crucial in transforming India's significant RE bearing mineral reserves into a strategic advantage, paving the way for a self-reliant future in critical mineral technology.

# Critical Mineral Scenario of India

**Dr. Arvind Kumar Mishra**

Director, CSIR-CIMFR Dhanbad



## Abstract:

Critical minerals are the cornerstone of modern technologies driving the clean energy transition, digitalization, and strategic sectors such as defence and aerospace. With India's rapid economic growth and ambitious climate targets, the demand for key minerals like lithium, cobalt, nickel, graphite, and rare earth elements (REEs) is projected to surge 4–5 times by 2030. Yet, India faces significant challenges—domestic extraction is nascent, leading to heavy import dependence (e.g., >90% for lithium, 100% for cobalt and >95% for REEs), creating strategic vulnerabilities to global supply shocks. India's geological landscape holds immense potential: recent discoveries include 5.9 million tons of inferred lithium (J&K), 6.9 million tons of REEs (mainly monazite in coastal sands), and significant graphite, nickel, and vanadium resources. However, these assets remain underexplored and underutilized due to gaps in upstream mapping, underdeveloped refining infrastructure, regulatory delays, and limited public–private coordination. Formal recycling and “urban mining” of e-waste and used batteries—critical for a sustainable supply—remain embryonic, with only 10–15% of e-waste formally recycled. Recognizing these challenges, the Government of India has launched several initiatives: the 2019 National Mineral Policy, the 2023 Critical Minerals List (30 minerals), the National Critical Mineral Mission (NCCM), and law amendments to encourage private/foreign participation and promote offshore exploration. India is building global alliances through MOUs (e.g., KABIL agreements in Argentina and Australia, participation in the US-led Mineral Security Partnership). Leading scientific organizations (CSIR labs, BARC, IITs) are advancing R&D in mineral extraction, battery recycling, and circular economy solutions. To secure India's critical mineral future, strategic action is essential: rapid exploration using advanced geospatial tools, investment in domestic processing and recycling, fostering innovation through centers of excellence, streamlined regulatory pathways, and international collaborations. Establishing a National Critical Mineral Authority, incentivizing private participation, formalizing urban mining, and building a national stockpile will underpin India's aspiration for energy sovereignty and economic resilience. In summary, a resilient and sustainable critical mineral value chain is vital for India's net-zero transition, national security, and global leadership in emerging technologies.

# Rare Earth Elements and its Applications

**Dr. Sandip Ghosh Chowdhury**

Director, CSIR-NML Jamshedpur



## Abstract:

Rare Earth Elements (REEs), comprising the lanthanides along with yttrium and scandium, are strategic critical minerals essential for advanced technologies. Their unique electronic, magnetic, and optical properties enable applications ranging from permanent magnets and catalysts to phosphors and medical imaging agents. In the context of Viksit Bharat, REEs are vital for accelerating clean energy transitions, strengthening digital infrastructure, and enhancing defense self-reliance. Neodymium, praseodymium, and dysprosium are key constituents of high-energy Nd-Fe-B magnets used in electric vehicle motors and direct-drive wind turbines. Europium, terbium, and yttrium are indispensable for phosphors in LED and display technologies, while erbium is critical for optical fiber amplifiers. In healthcare, gadolinium-based compounds are widely used as MRI contrast agents, and lutetium isotopes are emerging in targeted radiotherapy. Although India possesses considerable monazite- and xenotime-bearing placer deposits, particularly along the coastal regions, the country currently lacks large-scale separation and refining capacity, leading to heavy import dependence. To realize Viksit Bharat @2047, it is imperative to advance REE beneficiation technologies, establish recycling pathways from e-waste, and foster R&D in material applications. Strengthening the REE value chain will ensure strategic resource security, technological leadership, and sustainable industrial growth for India.

# Supply Chain Resilience of Critical Minerals – Inan Perspective

## Shri Mohan Babu Verma

Former Director AMD, Cons (T&I), NSCS



### Abstract:

Mineral resource distribution basically depends upon the country's geological setup, structure, tectonic conditions and depth of mineralisation. MoM has published a list of Critical minerals in 2023 which are either not available or their economic extraction is not feasible. Major Critical mineral resources such as lithium (Li), nickel (Ni), tungsten (W), niobium (Nb), cobalt (Co), molybdenum (Mo) and HREEs are not available in the country. Thus, overseas or off-take arrangements are required to meet their supply. Further, Critical minerals and rare earth (RE) resources are vital ingredients in technological transformation and development of advanced materials. Green energy transition to meet net zero emissions solely depends upon the availability of these mineral resources. COVID-19 and ongoing various conflicts are eye opener and stressed the requirement of the advanced material for strategic and commercial applications. Thus, the focus was shifted on supply chain of Critical mineral resources and development of advanced technology. In last two decades, China has emerged as major player and controls global supply chain of Critical minerals and REEs. China has developed indigenous mining, processing, separation, metal to alloy technology for most of the Critical minerals and their end products. Besides, China has heavily financed upcoming overseas projects in Africa and Latin American countries to have indirect control of global resources. Global transition in EV sector ends on China which produces >95% of magnets (NdFeB). China has also recently put an International embargo on supply of Ga, Ge, Sb and seven (7) REEs which includes Gd, Dy, Tb and Sm citing security concern and have global impact. To meet challenges of the current scenario, India needs focused exploration and identification of Critical minerals associated with polymetallic ore deposits. Association of gallium with bauxite, germanium in zinc ores, tungsten mineralisation with auriferous quartz veins, molybdenum (Mo) with U-deposits and Nb, Sr as by-products of RE deposit hosted in carbonatites. It needs extraction on commercial scale with the development of suitable technology. In Indian scenario, non-availability of Critical mineral resources will have major impact on 'Atmanirbhar Bharat' to boost indigenous manufacturing sector.

Recent efforts to strengthen indigenous supply chain, GMDC has been nominated as mining and exploiting agency to start first rare earth mine, hosted in Ambadungar Carbonatite Complex in Gujarat. In Rajasthan, Siwana Ring Complex (SRC) has also emerged as potential host of HREEs in micro granite and rhyolite. R&D in the Critical mineral sector needs startups, innovations and active role of private sector, rather dependency on the State. Opening of Centre of Excellence as a part of NCMM will probably open new avenues and accelerate the growth of the mineral sector. Innovation in process development to enhance metal recovery and treatment of low-grade ores will be the future key to augment Critical mineral resources.

Keywords: Critical mineral, rare earth, supply chain resilience and Centre of Excellence

# R&D needs for recovery of critical mineral values from mine and process wastes

**Dr. T. Sreenivas**

Former Head, Mineral Division,  
BARC Hyderabad



## **Abstract:**

Critical minerals have gained traction in the last decade across the world due to their indispensability in various materials, which are essential for technologies that aid in universal resolve to achieve the “below 20 C future” action plan of climate control. Generation and use of clean energy is one of the important vehicles in accomplishing the above target. Many studies have established that clean energy transition is highly mineral intensive. One of the World Bank reports estimated that over 3 billion tons of minerals and metals will be needed for the aggressive induction of different renewable energy technologies, including that of energy storage. Several drivers are identified for accomplishing the rising demand for minerals in a holistic manner and notable among them are: comprehensive extraction or valorization of mined material, economical use of energy and water, improving process efficiency, large-scale induction of green chemicals, reduction in the surface foot-print of waste/residues, integration of digital technologies etc. Implementation of the aforementioned measures in the domain of mineral processing of critical minerals is a daunting task. Nevertheless, encouraging progress has been made, at least on a conceptual and bench-scale, in this switch-over to new rules of the game world-over, including in India. The long gestation period for opening up any green-field mining project of critical minerals is pushing the stake-holders towards brown-field projects which include existing mines, abandoned mine dumps, process waste etc. which were hitherto not evaluated for their critical mineral value content due to a variety of reasons. This presentation makes an attempt to figure out some of the R & D steps needed for tapping the critical mineral content in brown field mines, like methodical mapping of resources, deciphering the deportation of values using conventional and advanced characterization methods, process intensification techniques in both physical beneficiation and hydrometallurgy, scope for use of green chemicals etc.

# Thermal Performance Enhancement in Sm-Co and Nd-Fe-B type Rare Earth Permanent Magnets

**Dr. Ranjan Singh**

Senior Scientist, DMRL Hyderabad



## **Abstract:**

Permanent magnets, in particular rare earth–transition metal magnets, have played a prominent role in the development of modern electrical and electronic devices. They are indispensable components in many modern devices due to their ability to offer high magnetic flux even in very small volumes. The two most commonly known rare earth permanent magnets (REPM) are sintered Neodymium-Iron-Boron (Nd-Fe-B) and Samarium-Cobalt (Sm-Co) magnets. While Nd-Fe-B magnets offer higher energy products, Sm-Co magnets provide superior thermal stability and corrosion resistance. This article reports the current strategies to develop high temperature grade Sm-Co and Nd-Fe-B type magnets primarily to meet the demands of modern strategic and civilian technologies. The thermal performance enhancement method includes alternative processing technologies and designing new alloy composition to reduce heavy rare-earth dependency in REPM magnets. Collectively, the trade-off between the two key magnetic parameters viz. remanence ( $B_r$ ) and coercivity ( $iH_c$ ) allow these magnets to be used effectively in increasingly high temperature operating environments.

Keywords: Rare Earth Permanent Magnet, Nd-Fe-B , Sm-Co

# Value Recovery From Red Mud For Circular Economy

## Shri Sagar Pandit

Function Head (Technical and R&D),  
Hindalco, Muri



## Abstract:

Red mud, also known as bauxite residue, is a highly alkaline by-product generated during the Bayer process for alumina extraction from bauxite. Globally, over 150 million tonnes of red mud are produced annually, with cumulative stockpiles exceeding 4 billion tonnes. Traditionally considered a hazardous waste due to its caustic nature and complex composition, red mud is increasingly being recognized as a valuable secondary resource—particularly for its significant content of rare earth elements (REEs), which are critical for modern technologies and the transition to a circular economy. The main chemical constituents of red mud are  $\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$ , and  $\text{CaO}$ . Apart from the base matrix, bauxite residue contains rare earth elements such as scandium, yttrium, lanthanum, cerium, and neodymium. Extensive research has been done globally on technology for recovery of values from red mud, but they have mostly been at the TR-01 & 02 level. With increasing demand for REEs in clean energy, electronics, and defense, and limited global supply, a research project was launched under the aegis of Niti Aayog with collaboration of Industrial partners, Hindalco, Vedanta and Nalco along with CSIR laboratories NML, IMMT and JNARDDC. The objective of this project was to develop a technology for holistic recovery of values such as  $\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$  along with REE's. A comprehensive process flowsheet was developed with stage wise recovery of  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{TiO}_2$  and finally recovery of Rare Earth Oxides using hydro-metallurgical and pyro-metallurgical processes and the process was scaled up to 10 kg and 100 kg red mud. This paper discusses Hindalco's views on overall process flowsheet for the recovery of values from red mud and the challenges in process engineering and scale up of the process. Authors would like to acknowledge the efforts of the project team from CSIR laboratories and industry partners from Hindalco, Nalco and Vedanta in developing this technology.

Keywords: Bayer, Circular Economy, Red Mud, Value Recovery.

# Advances in selective separation of critical metals - A necessity for emerging green technologies

**Dr. Ritesh Ruhela**

Bhabha Atomic Research Centre (BARC), Mumbai



## Abstract:

Development of a highly efficient critical metal separation technology is important in view of its potential applications in production of high purity critical metals as well as recovery of critical metals from low grade ores, lean process streams and secondary sources. Current metal separation technologies are based on either solvent extraction (liquid-liquid phase) or sorption (solid-liquid phase) processes. One of the most significant prerequisite of these technologies is design and development of metal selective ligands for their use as solvents in liquid-liquid extraction or as ligand grafted polymeric resin in sorption. To meet these challenges, a novel concept of molecular recognition technology based on structure activity relationship is currently being approached wherein subtle difference in ionic potentials and d/f orbital interactions of critical metals are exploited to achieve better separation factors.

In recent years another novel concept of task specific ionic liquids have emerged as green alternative for highly efficient critical metal separation, the major advantages offered are very low to negligible vapor pressure of ionic liquids, high chemical and thermal stabilities, ease of tuning of metals extraction properties, etc. Further, recovery of critical metals from lean process streams requires the development of highly selective sorbents for recovery of low (ppm range) concentration of critical metal from macro molar concentration of matrix ions. The present talk will highlight the recent activities on the development of advance technologies for highly efficient critical metals separations.

Keywords: Selective separation, critical metals, ionic liquids, ligand grafted resin

# Synergetic recycling of NdFeB magnets and Li-ion batteries

**Dr. Chenna Rao Borra**

Assistant Professor,  
Indian Institute of Technology Kharagpur



## Abstract:

Rare earth elements (REEs)-based (NdFeB) magnets and lithium-ion batteries (LIBs) are critical for a low-carbon economy. Their production depends on critical elements like REEs, Li, Co and Ni. Recycling of these products have been explored separately as a potential solution. Conventional methods for recycling NdFeB magnets and LIBs face challenges like high energy consumption, lengthy processing, excessive reagent usage, and waste generation. In this study, a novel synergetic recycling methodology is proposed to minimize these challenges. The idea is based on using waste ferrous sulfate solution generated during magnet leaching as a reducing and leaching reagent for battery recycling thereby eliminating the need for additional reagents for oxidation of iron in NdFeB and reduction of cathode material in LIBs. The magnet is leached in diluted H<sub>2</sub>SO<sub>4</sub> at 70 °C followed by double sulfate precipitation for REEs with Na<sub>2</sub>SO<sub>4</sub>. The REE-depleted but acidic ferrous solution is then used for reductive leaching of cathode material at 90 °C. The overall recovery rates of REEs, Li, Co, Ni, and Mn in this process are >95%. The iron from magnet material is recovered as crystalline and easily-filterable iron compound that can be converted to goethite and used as a byproduct. This synergetic approach not only reduces reagent consumption and waste generation aligning with the principles of circular economy but also offers improved efficiency, resource conservation, and environmental sustainability.

# Towards Circular Metallurgy: Recovery of Critical Metals from Ores, Wastes, and End-of-Life Products

**Dr. C Naveen Kumar**

Senior Principal Scientist,  
CSIR-Central Electrochemical Research Institute Karaikudi



## **Abstract:**

The rapid growth of modern technologies and clean energy systems has heightened the demand for critical metals such as lithium, cobalt, nickel, rare earths, and platinum-group elements. These metals are essential for batteries, electronics, catalysts, and strategic applications, yet their limited availability, uneven geographical distribution, and environmentally intensive mining processes pose significant challenges. To address this, extraction of critical metal values from both primary sources (ores, concentrates, and mineral deposits) and secondary sources (industrial by-products, end-of-life electronics, and spent batteries) has emerged as a sustainable pathway. Primary extraction approaches rely on advanced pyrometallurgical, hydrometallurgical, and electrochemical methods, while secondary recovery emphasizes urban mining, circular economy principles, and environmentally benign leaching and separation strategies. This dual-source approach not only reduces dependency on virgin resources but also minimizes waste generation, energy consumption, and carbon footprint. The integration of green solvents, bioleaching, plasma-assisted processing, and AI-driven optimization further enhances efficiency and selectivity in critical metal recovery. This presentation provides an overview of state-of-the-art methodologies for extracting critical metals from primary and secondary sources, and discusses future prospects for building resilient and sustainable metal supply chains.

# Abstracts

Oral Abstracts

# Significant occurrences of critical minerals in high ash content Indian coal

**Pramod Kumar Rajak, P. Zachamo Yanthana and Amitava Patra**

Sedimentology Research Group, Wadia Institute of Himalayan Geology, Dehradun, Uttarakhand (India).  
Department of Geology, Kohima Campus, Meriema, Nagaland University, Nagaland (India).

## Abstract:

The exploration of critical minerals and REE from alternative sources such as high ash yield coal has become extremely important. India's total estimated coal reserves (resources) as on 01.04.2023 are 378.21 billion tonnes (upto maximum depth of 1200 m) and about 98% of it is Gondwana while 2% Cenozoic (Tertiary) which includes lignite and sub-bituminous coal reserves found in various sedimentary basins. India ranks fifth in terms of reserves and second in terms of production. In this study, coal and its waste mainly ash were studied to evaluate the abundance and relationship of critical minerals and REE. Therefore, the results of quantitative analysis of critical minerals and rare earth elements in high ash coal samples in India would be important for determination through advanced analytical techniques. After getting encouraging results in these coals, the viable possibilities for its extraction should be assessed. For example, Jammu coal have high ash yield coal (3.72 to 43.22 wt. %,  $\bar{x}$  = 27.16 wt. %) and content of several critical mineral and Rare Earth Elements (REEs) have significant amounts like Co ( $\bar{x}$  = 11.8 ppm), Ga ( $\bar{x}$  = 15.24 ppm), Li ( $\bar{x}$  = 1163.05 ppm), Pd ( $\bar{x}$  = 42.45 ppm), Sc ( $\bar{x}$  = 11.3 ppm), Se ( $\bar{x}$  = 11.08 ppm), Sr ( $\bar{x}$  = 173.19 ppm), V ( $\bar{x}$  = 79.31 ppm) and Y ( $\bar{x}$  = 10.22 ppm) from whole coal samples in this coal are higher than the world average values. In particular, some of these critical elements exhibit remarkably high economic value, requiring careful consideration for extraction through various scientific tools.

Keywords: Critical minerals, Rare Earth Elements, Ash Yield, Extraction.

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## Recovery of Rubidium, Caesium and Potassium from the Leach Residue of Indian Pegmatite Ore

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## Abstract:

Rubidium (Rb) and Caesium (Cs), used in the speciality electronics and chemical applications, are recovered as by products from other ores due to their low concentrations and dispersed geochemical occurrence. Potassium (K) finds application in fertilizers, pharmaceuticals, and electronics.

This study investigates salt roasting followed by water leaching to recover Rb, Cs and K as by-products from the leach residue of pegmatite rock previously subjected to sulphation roasting and water leaching for the recovery of Li. The ore mainly contained Lepidolite, Muscovite, K-feldspar, Albite, and Quartz. The ore was initially subjected to sulphation roasting with moderate dosages of additive for short durations at 1000 °C, followed by leaching for extraction of Li into aqueous phase. The leach residue contained 0.41%Rb, 0.11%Cs, and 4.14%K. The attempts to recover Rb, Cs and K necessitated prolonged roasting and higher additive dosages to optimize yields of aforementioned metals as by-products. Due to these limitations, a chlorination roasting approach was employed on leach residue, varying roasting temperature (700–1000°C), time (1–5h), and additive dosages (NaCl: 0–132kg/t; CaCl<sub>2</sub>·2H<sub>2</sub>O: 0–662kg/t), along with leaching parameters such as temperature, time, and pulp density. Characterization of roasted and leached samples revealed additive–phase interactions, phase transformations influenced by temperature and dosage. Chlorination roasting decomposed the original residue phases, forming anorthite, quartz and water-soluble alkali chlorides, which enabled leaching of Rb, Cs and K from residue obtained after recovery of Li. Recovery of each of these metals was over 85%.

Keywords: Chlorination roasting, Water leaching, Alkali metals, Phase transformation

## **Strategic Assessment of Rare Earth Element Potential in Coal Ash from Singrauli Coalfield, India for Resource Development**

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### **Abstract:**

Rare Earth Elements (REEs) designated as critical minerals, are essential for advanced technologies and clean energy solutions. However, their conventional supply is constrained necessitating exploration of alternative resources. This study investigates coal ash from ten mines of the Singrauli Coalfield, India, to assess its potential as a secondary REE source. Coal samples were ashed at laboratory scale and digested following ASTM D6357 protocols. Major, trace, and REE concentrations were analyzed, focusing on exploration-stage differentiation among the mines to guide future targeted recovery strategies. The REE-bearing phases in these sub-bituminous coals are associated with minerals such as kaolinite, quartz, and fluoroapatite. Among the ten mines analyzed, Dudhichua (582.30 ppm), Nigahi (546.58 ppm), and Block-B (538.63 ppm) exhibited the highest total REE concentrations in ash exceeding the global cut-off (300 ppm) for potential economic extraction.

Other mines include Amlori (536.93 ppm), Krishnashilla (528.76 ppm), and Jayant (507.06 ppm), all of which indicate promising extraction feasibility. These values are significantly higher than many globally reported coal ash REE contents, particularly in neodymium (71.43 ppm), which is a key component in wind turbines and electric vehicles. Provenance indicators  $\text{Al}_2\text{O}_3/\text{TiO}_2$  (15.85) suggest an intermediate to felsic igneous source for the sediments, correlating with elevated REE concentrations. This systematic mine-wise REE inventory provides a critical baseline for prioritizing resource development, offering actionable insight for future industry-led recovery projects. The results position Singrauli as a viable REE source region, with implications for India's strategic mineral security and clean energy initiatives.

Keywords: Rare Earth Elements, Critical Mineral, Singrauli Coalfield

## **Towards indigenous cobalt production through recovery from secondary sources**

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### **Abstract:**

As India accelerates its transition to electric mobility and battery-based energy storage, securing critical minerals like cobalt from domestic sources is essential for building a reliable and sustainable supply chain. This study presents a hydrometallurgical flowsheet for the recovery of high-grade cobalt oxide from zinc plant residue (ZPR), a secondary resource containing ~2.6 wt% cobalt. The four-step process includes: (i) leaching in dilute sulphuric acid (>90% Co and >95% Zn recovery at ambient conditions); (ii) selective cementation of Cu and Cd using Zn dust; (iii) oxidation-precipitation of Fe using sodium persulfate and lime; and (iv) final precipitation of cobalt hydroxide, yielding a product with ~58 wt% cobalt. Overall, cobalt recovery exceeded 85%, and the process generated zinc-rich filtrate (68–70 g/L) that can be reused in the primary Zn production circuit.

This study, positioned within India's broader policy push for securing critical minerals, demonstrates a viable pathway for producing cobalt from residues. It aligns with the components of the National Critical Minerals Mission, especially the recovery of critical minerals from mine tailings and industrial residues. With further refinement, this flowsheet could be integrated into pilot-scale facilities, offering a scalable solution for domestic production and reducing India's dependence on cobalt imports.

Keywords: Critical minerals; Cobalt production; Leaching; Oxidation precipitation

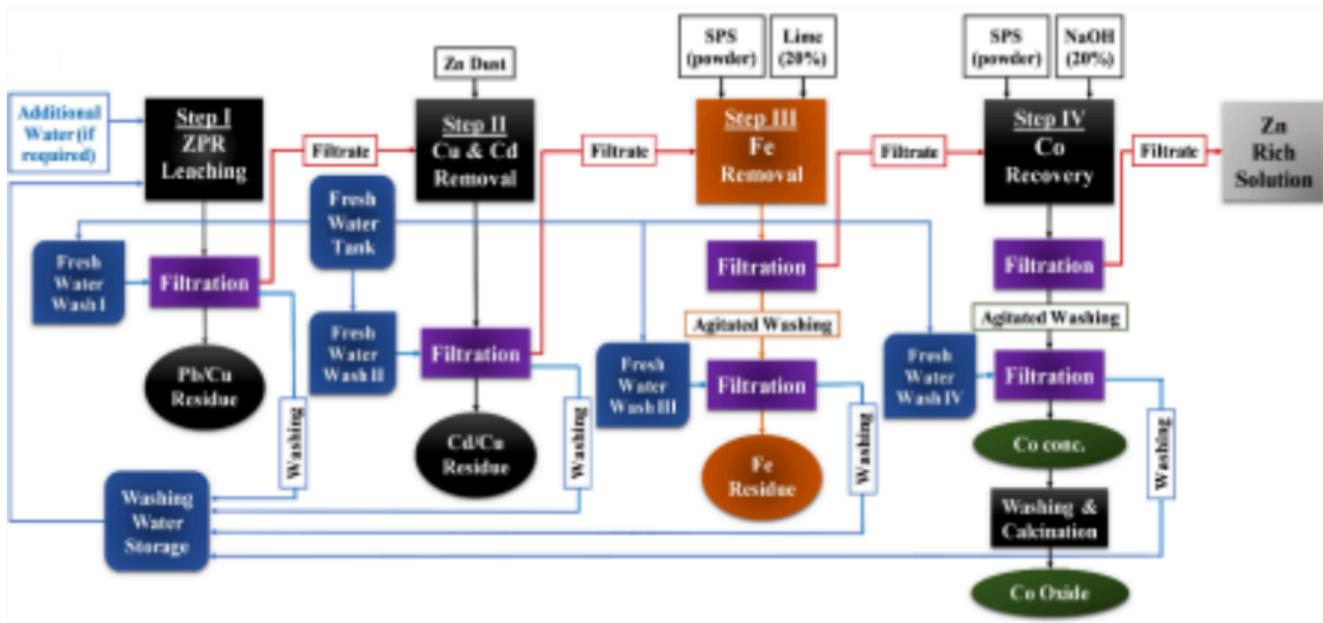


Figure 1: Proposed flowsheet for cobalt recovery from acid leaching of ZPR, purification using zinc dust cementation of copper and cadmium, and oxidation and precipitation of iron and cobalt using SPS (sodium persulfate)

## Coal Washery Rejects: Potential secondary resource for rare earths extraction

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### Abstract:

Rare Earth Elements (REEs), including scandium and yttrium, are essential for modern technologies, particularly in green and strategic industries. However, their global supply is limited, and Indian industries rely heavily on imports (>95% in 2021). This dependency highlights the urgent need to identify alternative domestic resources for REEs beyond conventional ores. Coal Washery Rejects (CWR), a by-product of coal beneficiation, represent one such potential resource due to their high inorganic content. Bulk samples of CWR were collected from the coal washery and analyzed using ICP-MS, TGA, and XRD techniques. It reveals the presence of minerals such as illite, kaolinite, monazite, and hematite, which are possible hosts for REEs. Elemental analysis indicated REE concentrations ranging from 300–600 ppm as TREEs. Most of REEs belongs to LREE group. Laboratory-scale extraction was also investigated using hydrometallurgical methods. Leaching experiments employing various inorganic acids (HCl, HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>) were conducted, optimizing parameters such as acid concentration, particle size, temperature and other factors. Initial recoveries reached up to 32% in presence of inorganic acids. To enhance extraction efficiency, alkali roasting was introduced as a pre-treatment step at temperatures between 300–800 °C, followed by optimized leaching. This approach improved REE recovery to approximately 50%. Although research is ongoing, the findings suggest that CWR, often considered a waste material, can be transformed into a promising secondary resource of REEs. Integrating such recovery strategies could not only mitigate India's dependence on imports but also contribute to the economic and sustainable utilization of coal waste products.

## Hydrometallurgical processing of spent HDS catalyst for recovery of critical metals

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### Abstract:

Vanadium is one of the important critical metals that is extensively used as additive in steelmaking, energy storage, H<sub>2</sub>SO<sub>4</sub> production and aviation industries due to excellent corrosion resistance and high strength. The demand of vanadium is increasing continuously, however the primary resources of vanadium in India are very limited to few sites and not yet explored. Therefore, the secondary resources containing vanadium becomes important to meet the domestic demand of country. The spent hydrodesulfurization (HDS) catalyst generating from petrochemical industries contains suffice amount of vanadium, Therefore, the present investigation is focused on the hydrometallurgical extraction of vanadium from the spent HDS catalyst. The spent catalyst sample received is characterized using XRD and ICP-OES. The chemical analysis results show the presence of 11.2 % of vanadium along with other valuable metals such as Mo, Ni, Al, P and some trace metals like Co, Mg, S etc. Studies have been carried out for effective and selective recovery of vanadium from spent catalyst using alkali roasting followed by water leaching. Different roasting parameters such as temperature, time, amount of alkali addition etc. have been optimized for quantitative recovery (92%) of vanadium metals. Further, the metal was precipitated from the leach liquor using using NH<sub>4</sub>Cl. Thus, the present study is focused on the development of a sustainable process for selective recovery of vanadium from spent HDS catalyst.

Keywords: Critical Metal, hydrodesulfurization, spent catalyst, hydrometallurgy, metal recovery

## Debromination of waste printed circuit boards through a zero-discharge solvothermal process

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## Abstract:

Given the growing consumption and frequent replacement of electronic gadgets, global electronic waste (e-waste) is expected to reach ~70 metric tons by 2030 [1]. Sustainable development requires mandatory e-waste recycling technologies. Waste printed circuit boards (WPCBs) contain valuable metals (~30%), making targeted metal extraction from e-waste a focus of interest [2]. On the other hand, non-metallic fraction (~ 60-70%) of PCBs are seldom recycled, and are mostly discarded. The non-metallic fractions of e-waste consist of valuable phenolic/epoxy resins and glass fibers. However, recycling is challenged by stable halogen based compounds, especially Brominated Flame Retardants (BFRs), which are deliberately added to meet high-flammability standards in electronics. Hence, conventional recycling of PCBs by pyrometallurgical routes would cause formation of toxic/carcinogenic byproducts such as dioxins and furans.

In this work [3], we present a safe, simple, cost-effective, energy-efficient, and eco-friendly process for the debromination of waste printed circuit boards. The debromination is achieved through a simple solvothermal process, which yields efficient removal of BFRs from the non metallic fraction of WPCBs at relatively low temperatures (less than 200 °C) and atmospheric pressure using organic solvents. The use of a suitable catalyst helps to achieve a debromination efficiency of more than 90%. Our experiments suggest that the proposed process is amenable to a zero-discharge approach while ensuring scalability, making it both eco-friendly and sustainable. Therefore, it would benefit a wide range of industries by enabling the recycling of end-of-life PCBs, Br-free plastics would be easily vaporizable, which would benefit multiple industries that use glass fibers.

Parameters such as temperature, time, amount of alkali addition etc. have been optimized for quantitative recovery (92%) of vanadium metals. Further, the metal was precipitated from the leach liquor using using  $\text{NH}_4\text{Cl}$ . Thus, the present study is focused on the development of a sustainable process for selective recovery of vanadium from spent HDS catalyst.

Keywords: Waste printed circuit boards (WPCBs), Solvothermal debromination, Zero discharge approach, Sustainable development goals (SDG 8, 9, 11, 12 and 15)

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## Lithium-Ion Battery Recycling in India: A Perspective

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## Abstract:

The rapid growth of electric vehicle adoption and renewable energy integration in India is driving an unprecedented demand for lithium-ion batteries (LIBs).

While LIBs are pivotal for reducing carbon emissions and achieving energy sustainability, the resulting surge in end-of-life battery volumes presents significant environmental and resource management challenges. India, heavily dependent on imports for critical battery materials such as lithium, cobalt, and nickel, faces a pressing need to develop a robust recycling ecosystem to enhance material recovery, reduce supply risks, and promote circular economy principles. Despite existing policy frameworks, such as the Battery Waste Management Rules (2022), and emerging industry initiatives, India's recycling infrastructure remains underdeveloped, with challenges in collection logistics, technological readiness, and the safe handling of hazardous waste. Leveraging advanced recycling technologies, fostering formalized industry participation, and strengthening regulatory enforcement are crucial to unlocking economic opportunities, securing raw material supply, and mitigating environmental impacts. This review underscores the importance of collaborative efforts among government, industry, and research institutions to build scalable, efficient, and sustainable LIB recycling systems that support India's ambitions for clean mobility and energy self-reliance.



Fig 1. Key pillars of sustainable lithium-ion battery management: recovery, recycling, circular economy, storage, e-waste, and policy

Keywords: Battery recycling, Sustainability, Hydrometallurgy, Pyrometallurgy, Direct recycling

## Evaluation of geochemistry and mineralogy of critical minerals in Indian coal deposits with emphasis on enrichment of REEs

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### Abstract:

Critical minerals (CMs) are those materials which are essential for modern technology, economic development and national security. In the era of digital industrialization and green technologies, the world needs to explore the alternative sources of CMs.

Scientific research have already proved that the coal deposits are alternative sources of some critical elements which are Ge, Ga, Nb, Zr, Ta, rare earth elements (REEs) and platinum group elements (PGEs).

The factors responsible for elemental enrichment in coal deposits are, (i) injection by infiltration and exfiltration of metal rich solutions; (ii) insertion of volcanic ashes; (iii) input of terrigenous materials; (iv) metal leaching of partings; and (v) mixed processes of hydrothermal solutions and volcanic ash. The highest enrichment of REEs in Russian coal have been measured to be 2454 mg/kg and 17026 mg/kg on whole coal basis and ash basis respectively. The REEs in Chinese coal reached up to 2446 mg/kg and 5686 mg/kg on whole coal basis and ash basis respectively. The REEs content in Mongolian coal also enriched up to 5178 and 13723 mg/kg on whole coal basis and ash basis respectively. The maximum REEs in India has reached up to 1446.11 mg/kg in coal ash from eastern coalfield.

In this article, we have discussed the potentiality of coal deposits as alternative source of CMs as well as REEs. The REEs in the generated coal ashes are much higher than the cut off range (667 to 762 mg/kg) for beneficial extraction of REEs from coal ash. CMs like Ga, Ge and REEs are mobilized and enriched in CFA and BA generated from thermal power plants. The cut-off grade for economical extraction of Ge from coal ash is 300 mg/kg. The present article also highlights the mineralogical characteristics and mode of occurrence of CMs in coal, CFA and BA.

Keywords: Critical minerals, rare earth elements, coal, coal ash, thermal power plants.

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## **DEVELOPMENT OF PROCESS FLOWSHEET FOR LITHIUM RECOVERY FROM LEPIDOLITE ORE OF BIHAR MICA BELT**

**Reshu Sinha, Atchutanna Vidyaadhari, Ajay Kumar, Dharavath Dev, Anand Rao K**

Mineral Processing Division, Bhabha Atomic Research Centre

### **Abstract:**

This study presents details of exhaustive experiments conducted on lepidolite ore for the recovery of lithium, integrating pyrometallurgical and hydrometallurgical techniques. Lepidolite ore from the Bihar mica belt was utilized in this investigation. Three distinct process routes were evaluated to maximize the recovery of lithium. The first route involved direct roasting of the ground ore with sulfuric acid, followed by plain water leaching. In the second route, the ore was calcined at 900°C, followed by sulfuric acid roasting at 350°C and subsequent plain water leaching. The third route employed salt roasting using a mixture of Sodium sulphate (Na<sub>2</sub>SO<sub>4</sub>) and Calcium sulphate (CaSO<sub>4</sub>) salts with ground lepidolite ore, and plain water leaching of the roasted mass. Parametric variations were carried out across all three routes to maximize the recovery of lithium values.

Among the three process routes examined, the salt roasting route was found to have several advantages during the roasting, leaching, and impurity removal steps. Hence, the leach liquor generated in the salt roasting route was further investigated for down-stream operation, which include Lithium Carbonate ( $\text{Li}_2\text{CO}_3$ ) precipitation, purification of lithium carbonate, conversion of  $\text{Li}_2\text{CO}_3$  to Lithium Hydroxide ( $\text{LiOH}$ ) and precipitation of the final product, Lithium Hydroxide Monohydrate ( $\text{LiOH}\cdot\text{H}_2\text{O}$ ). The results indicated the possibility of an overall lithium recovery of ca. 82% in the final product, with  $\text{LiOH}\cdot\text{H}_2\text{O}$  purity reaching 99.23%. Additionally, trace recovery of rubidium and cesium present in the lepidolite ore was observed in the salt roasting route. However, the scope of this study remained on optimizing lithium recovery. The findings provide novel insights into process efficiency and impurity removal in the extraction process of lithium values from lepidolite ore, contributing to sustainable resource utilization and green extraction technologies.

Keywords: Lepidolite ore, Lithium recovery, Salt roasting, Lithium hydroxide monohydrate

## **Studies on recovery of rare earth elements from coal fly ash of Indian origin using hydrometallurgical techniques**

**Ram Karan, Anuj Kumar Singh, Ajay Kumar M, Dharavath Dev, K Anand Rao**

Mineral Processing Division, Bhabha Atomic Research Centre

### **Abstract:**

This paper presents the studies carried out on the recovery of Rare Earth Elements (REE) from Coal Fly Ash (CFA) of thermal power station of Neyveli, Tamilnadu, India. The sample assayed about 1400 ppm of total REE of which 25% is contributed from Heavy REE (HREE), which are very scarce in primary resources. Apart from good concentration of HREE, the CFA contains nearly 28% of REE, useful in making permanent magnets. The major portion of gangue matrix includes  $\text{SiO}_2$  – 45%,  $\text{Al}_2\text{O}_3$  – 23%,  $\text{Fe}_2\text{O}_3$  – 11% and 6.4%  $\text{CaO}$ . Detailed leaching studies were carried out using  $\text{HCl}$ , with the special emphasis on measurement of filtration rates of leach slurry (Figure 1) and scalability of the process to industrial scale. About 65% of the total REE could be dissolved successfully under optimum conditions. The gel formation issue was avoided by selective removal of silica by pH adjustment using  $\text{CaO}$ . REE from the leach liquor were recovered by precipitation technique using oxalic acid, which resulted in a poor grade product of total REE – 2%, which was subsequently purified. The complete process scheme developed resulted in the recovery of about 60% total REE present in the coal fly ash. The REE concentrate product produced by following this process scheme assayed about 42% REO. The process scheme adopted includes hydrometallurgical techniques that are easily scalable to industrial scale.

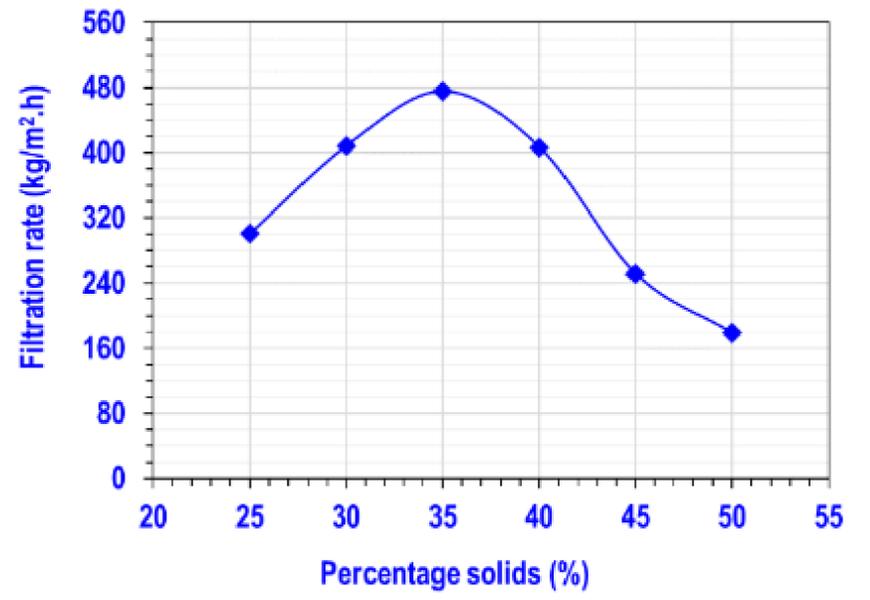
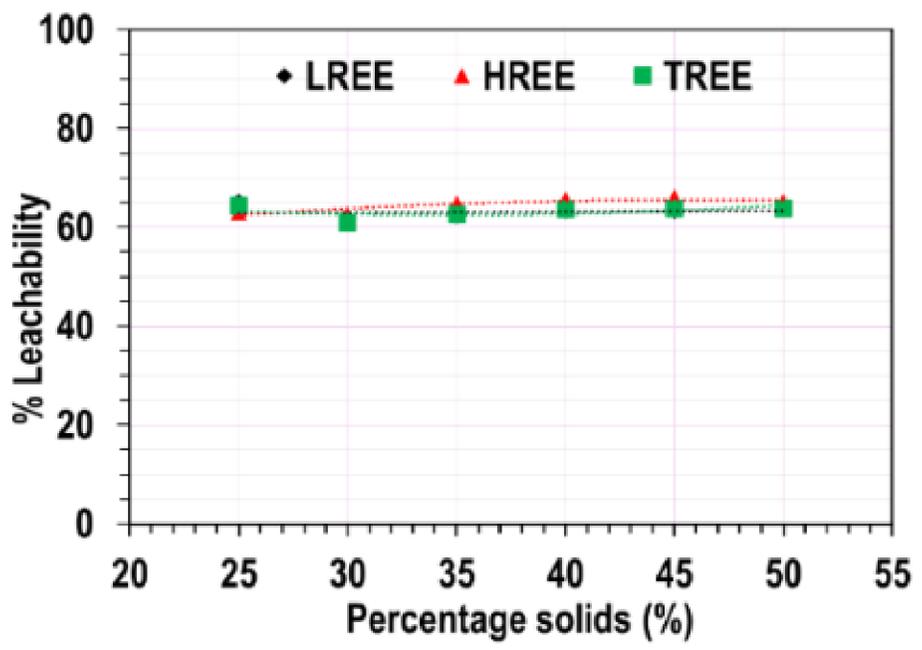


Figure 1: Effect of percentage solids on (a) leaching efficiency of REE (b) filtration rate of leach slurry



# Abstracts

Poster Abstracts

# Bio-based Approaches for Critical Metal Extraction: An Environmental and Economic Evaluation

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## Abstract:

The growth of the green energy transition and advanced technologies has escalated the demand for critical metals (CMs), which are associated with environmental concerns such as extraction and conventional mining, thus prioritizing the growth of sustainable substitutes (Szanyi et al., 2023). Bio-Based methods, including biosorption, bioleaching, and Phyto mining, give promising paths for critical method recovery from low-grade ores (primary sources) and industrial tailings, e-waste, and wastewater (secondary sources) (Balaram 2023). Bio-based approaches are environmentally friendly and exhibit a great significance over the traditional methods, such as hydrometallurgical and pyrometallurgical processes (Balaram 2023). They classically function under low pressure and temperature (milder conditions), reducing the demand for hazardous chemicals, less energy is consumed, and a smaller amount of greenhouse gas (GHG) and less toxic waste is generated (Najiha et al., 2016). Their ecological advantages are further highlighted by the possibility of bioremediation of contaminated locations and the recovery of metals from intricate matrices like e-waste (Islam et al., 2020). Life cycle studies frequently show that bio-based extraction has a smaller environmental impact, promoting resource circularity and reducing water pollution and land degradation (Szanyi et al., 2023). A number of variables, including ore grade, microbial efficiency, process scalability, and the target metals' market value, are critical to the economic feasibility of bio-based CM extraction (Palladino et al., 2023). Although setting up bioreactors and related equipment can require a sizable initial capital investment, ongoing expenses are often lower due to the decreased need for chemical reagents and electricity (Palladino et al., 2023). Studies have shown that bioleaching, in particular, is economically feasible for some metals, with positive internal rates of return (IRRs) and net present values (NPVs) for operations on a commercial scale. There are still issues with establishing reliable pre-treatment plans for complicated feedstocks, optimising process kinetics, and consistently reaching high metal recovery rates. However, economic competitiveness is constantly being improved by developments in microbial consortia engineering, process intensification, and integration with traditional techniques (hybrid bioleaching). To sum up, bio-based methods for crucial metal extraction are an appealing and increasingly practical example. They are essential technologies for sustainable resource management because of their intrinsic environmental advantages. Although economic optimisation is a continuous process, research advancements and pilot-scale applications indicate that these techniques will be crucial in ensuring future CM supply while reducing environmental effects.

Keywords: Critical Methods, Bio-Based Approach, Environmental Challenges, Traditional Methods

## Hydrometallurgical Recovery of Rare Earth elements From Spent NdFeB Magnet

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### Abstract:

Rare earth elements (REEs) are critical materials widely used in permanent magnets, electric vehicles, wind turbines, and advanced electronics due to their unique magnetic, optical, and catalytic properties. However, the growing global demand, limited primary resources, and environmental concerns associated with conventional mining have intensified interest in sustainable recovery of REEs from secondary sources such as NdFeB magnet waste. The process was initiated with a leaching stage, employing 1.8 M HCl, 5% pulp density, 300 rpm at 90 °C, which effectively dissolved the rare earth components into solution. The resulting leach liquor contained significant concentrations of iron along with REEs. To purify the solution, a two-component precipitation system using Sodium hydroxide successfully precipitated iron impurities at a controlled pH of 3.5, resulting in a clear, REE-rich solution. Solvent extraction was then carried out using 1 M di-(2-ethylhexyl) phosphoric acid (D2EHPA), which selectively loaded REEs into the organic phase. REEs were subsequently stripped using 10% sulfuric acid, producing a concentrated aqueous REE solution. Oxalate precipitation was performed using 2.5 M oxalic acid, leading to the formation of dense rare earth oxalates. The precipitate was then subjected to calcination at 800 °C for 2 hours, resulting in the formation of high-purity rare earth oxides.

Keywords: Rare earth, Permanent Magnet, Leaching, Solvent Extraction, Precipitation

## Hydrometallurgical processing of waste NdFeB magnets for rare earth recovery using solvent extraction techniques

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### Abstract:

The reclamation of rare earth elements (REEs) from end-of-life NdFeB permanent magnets is critical for sustainable resource utilization and mitigating reliance on primary mineral extraction. NdFeB permanent magnets are the most resilient type of permanent magnets commercially available and are used in numerous devices like wind turbine, electric vehicles, hard disk drives, smart phones etc.

NdFeB waste magnet scarp obtained from wind turbines contains a generous amount of rare earth elements like Nd, Pr and Dy, which raises a concern about the recycling of these waste scarps. A hydrometallurgical route has been developed to recover REEs from the chloride leachate of NdFeB magnet scrap, which also contains boron (B), iron (Fe), and cobalt (Co). Prior to REEs extraction, iron is removed as  $\text{Fe}(\text{OH})_3$  through precipitation with  $\text{H}_2\text{O}_2$  as the oxidant and  $\text{Ca}(\text{OH})_2$  as precipitating agent, ensuring minimal interference in subsequent steps. Afterwards, the recovery of REEs from iron free liquor through solvent extraction was attempted using an appropriate extractant to selectively separate REEs from other impurities, followed by stripping with  $\text{H}_2\text{SO}_4$  to recover REEs as pure sulphate solution. Selective precipitation is conducted to isolate REEs from the stripping solution. Finally, the precipitated REEs are calcined to obtain high-purity rare earth oxides. This integrated process offers an efficient approach to the recovery of valuable REEs from waste NdFeB magnets.

Keywords: Solvent extraction, NdFeB Magnet, precipitation, Rare earth elements (REEs)

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## Separation and Recycling of Rare Earth Elements from NdFeB Waste Magnets: A Critical Metals Perspective

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### Abstract:

Rare earth elements (REEs) are essential for high-performance technologies, yet their supply is constrained by geopolitical and environmental challenges. Recycling of REEs from end-of-life NdFeB magnets offers a sustainable solution to reduce dependency on primary resources. This study presents an integrated recovery approach that transforms NdFeB waste into valuable materials. The process involves mechanical comminution followed by leaching with  $\text{H}_2\text{SO}_4$ , achieving >98% REEs and Fe recovery and >95% B recovery. Iron is effectively removed via selective precipitation using  $\text{Ca}(\text{OH})_2$  with minimal REE loss. High-purity separation of Nd, Dy, and Pr is accomplished through solvent extraction using organophosphorus extractants. The precipitation of REEs with oxalic acid and thermal conversion yields REE oxides with >95% purity. The optimized route ensures over 90% overall REE recovery with reduced reagent consumption, and minimal waste generation. This work highlights the potential of REEs recycling from NdFeB magnets, promoting resource efficiency and aligning with circular economy goals.

Keywords: Rare earth elements, NdFeB magnets, solvent extraction, sustainable recovery

# Sustainable Vanadium Recovery from Bayer's Sludge using Choline Chloride-based Deep Eutectic Solvent DES: A study based on experimental and computational approach

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Department of Fuel, Minerals and Metallurgical Engineering, IIT(ISM) Dhanbad

## **Abstract:**

The rising demand for strategic metals such as vanadium, a precious, infrequent metal with very scarce resources available in the earth's crust, has necessitated the development of sustainable recovery techniques from various secondary resources. Bayer's sludge obtained during the production of alumina from bauxite is a crucial source containing 10-20 % of vanadium in the form of Vanadium pentoxide. The present study employed Choline Chloride-based Deep Eutectic Solvents (DESs) as green and tunable media for the selective leaching of vanadium from Bayer's sludge. Several DESs were synthesized using choline chloride as the hydrogen bond acceptor and organic acids such as oxalic acid, malonic acid, ethylene glycol, and urea as hydrogen bond donors [1]. Leaching experiments were conducted under varied conditions, including pulp density, temperature, and agitation, to evaluate metal dissolution efficiency. The leachates were analysed using ICP-OES after suitable dilution and filtration procedures. Density Functional Theory (DFT) calculations were also employed to study the interaction of vanadium's various oxidation states and other metal ions with deep eutectic solvent (DES) components. Optimized geometries and hydrogen bonding analyses were carried out to understand the structural and electronic characteristics of metal-DES complexes [2]. This combined experimental and theoretical approach provides valuable insights into the mechanism of selective leaching of vanadium over other metal ions from sludge. It highlights the potential of DESs as eco-friendly media have been studied for critical metal recovery.

Keywords: Bayer's sludge; Vanadium; DES; DFT

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## **Organic acid leaching of critical metals from copper extraction process wastes**

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Department of Environmental Science and Engineering, Indian Institute of Technology (ISM) Dhanbad, India.  
Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, India

## **Abstract:**

A hydrometallurgical method incorporating organic lixiviants is explored for the selective extraction of critical metals, including copper, cobalt, and nickel, from copper extraction process waste (ESP Dust, Copper slag, and Copper tailings).

The main objective of this investigation is to determine the leaching behaviour of these wastes with an organic acid to recover the valuable critical metals. The process begins with the leaching of the CEPW using organic solvents, including acetic acid, citric acid, and organosulfonic acid, to recover copper, cobalt, and nickel selectively. The synergistic effect of parameters like time, type of acid, and the waste type was observed. The optimized conditions varied for the target critical metal in a specific type of waste and indicated selectivity of the process. The variability in recovery depended on the sample type, acid used, and temperature. Organosulphonic appears most effective for Ni and Co, while citric acid shows promise for Co. Acetic acid is less effective overall. The leaching behaviour of the metals from the wastes was thoroughly investigated by the XRD and SEM–EDAX studies of the residues.

Keywords: Copper extraction process waste, Waste recycling, Environmental management, Organic leaching

## Global Insights for Sustainable Lithium Mining Practices in India's Critical Mineral Mission

Ridhee Ghosh, Dr. Biswajit Paul

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### Abstract:

The accelerating demand for lithium, driven by the global shift toward EV mobility, renewable energy storage, and advanced electronics, has spiked exploration and mining worldwide. Lithium, often termed “White Gold”, was thought to be an excellent solution to combat greenhouse emissions. With passing time, it has been observed that lithium mining has been connected to various environmental and socio-economic challenges, including groundwater depletion in arid salt flats, biodiversity loss, and disputes with indigenous communities over land and water rights. Recently, a few sites have been identified as a potential reserve of lithium by GSI. India is very new to this commodity, lacks lithium-specific baseline environmental data, an EIA framework, and policies, which poses a risk of repeating the global mistake.

The study synthesizes the lessons learned from established producers like Australia (hard rock mining), Chile, and Argentina (brine Extraction) to identify a sustainable EIA framework for the Indian context. Recommended policy enhancement that should mandate water use thresholds tailored to local hydrogeology, enforceable ecological monitoring plan for the life of each project. Embedding these safeguards into India's National Critical Minerals Mission can ensure domestic resource security and environmental sustainability.

Keywords: Lithium, Environmental Impact Assessment, EIA, Critical Mineral Policy

# Selective-Oxidative Leaching of Copper and Zinc from Spent Industrial Catalysts

Renuka Bommi , Lutukurthi. D. N. V. V. Konda

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## Abstract:

Solid catalysts play an important role in fertilizer and chemical industries. However, the problem is that large quantities of spent industrial catalysts containing high concentrations of valuable metals are discarded from the industries as solid waste, which is hazardous and pollutes the environment. Considering the limited resources of valuable metals and the issues with discarding spent catalysts, recovering valuable metals from spent industrial catalysts is an attractive option for recycling and utilization. This study explores the hydrometallurgical recovery of copper and zinc from spent low-temperature shift (LTS) catalysts composed of CuO, ZnO, Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, and SiO<sub>2</sub>. The effect of key process parameters such as acid concentration (eq/L), solid-to-liquid ratio (g/cc), leaching duration (hours), and temperature (K) on the leaching of metals and optimized leaching parameters were identified using spent catalyst material of particle size below 100 μm under controlled agitation (200–250 rpm). Further, selective leaching of Cu and Zn and oxidative leaching of Fe were successfully achieved while leaving TiO<sub>2</sub> and SiO<sub>2</sub> gangue in the residue left over after leaching. The optimized leaching conditions resulted in extraction efficiencies of 96.8% for CuO, 98.5% for ZnO, 98.4% for Fe<sub>2</sub>O<sub>3</sub>, and 21.5% for Al<sub>2</sub>O<sub>3</sub>. All the leaching experiments were performed by maintaining 99.9% of Fe in its highest oxidation state (Fe<sup>3+</sup>) for enhanced separation and potential downstream recovery of copper and zinc from the leachate.

Keywords: Spent catalyst, Cu and Zn, Selective leaching, Hydrometallurgy, Metals recovery

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## Global Research Trends on Critical Elements in Coal Ash (2015-2025): A Bibliometric Perspective

Kumari Saumya, Biswajit Paul

Department of Environmental Science and Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, 826004, India

## Abstract:

Critical elements, particularly rare earth elements (REEs), are essential for supporting the global economy and advancing emerging technologies. The depletion of primary mineral deposits has intensified the search for secondary sources. Among these, coal ash, a byproduct of coal combustion, has emerged as a potential alternative resource, containing appreciable concentrations of these elements.

Some countries, such as China, have already initiated an industrial-level recovery from coal ash, underscoring its potential.

This study aims to analyse global academic research on critical elements in coal ash from 2015 to 2025 using bibliometric methods. A total of 3,932 publications were collected for this period, showing an overall increasing trend and peaking in 2024. The data set was compiled using the advanced search formula TS (Topic) = (“Critical mineral” OR “Rare Earth Elements”) AND (“Recovery”) AND (“Coal Ash”) in the Web of Science (WoS) to identify relevant scientific studies. The bibliometric analysis evaluated the public trends, leading journals, research areas, WoS categories and keywords to identify evolving research hotspots and future trends. Findings indicate a consistent upward trend in publications, with growing emphasis on environmentally sustainable extraction technologies and supply chain integration. Results highlight coal ash as a viable alternative source of critical elements, offering an opportunity for both environmental remediation and strategic resource security. This bibliometric provides a foundation for guiding future research and policy initiatives towards the sustainable recovery of critical elements from coal ash.

Keywords: Critical elements; Rare earth elements, Coal ash, Bibliometric analysis

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## **Carbonate-hosted pyrites, Bhima Basin, Karnataka- a prospect for exploring Critical Metals**

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Exploration Geology Lab., Dept. of Applied Geology, Indian Institute of Technology (Indian School of Mines)  
Dhanbad-826004, Jharkhand

### **Abstract:**

The accelerating global demand for critical minerals, driven by clean energy technologies, advanced manufacturing, and strategic defence applications, underscores the necessity for sustainable sourcing through exploration, recycling, and innovative processing. Trace elements like selenium (Se), molybdenum (Mo), cobalt (Co), and nickel (Ni) are of particular interest due to their roles in photovoltaics, semiconductors, superalloys, battery cathodes, and catalytic systems. In the Proterozoic Bhima Basin of Karnataka, India, Pyrites hosted by shallow marine carbonate sequences comprising limestones host trace to sub-economic concentrations of these metals. Their occurrence is linked to depositional environments with anoxic to sub-oxic conditions, favouring metal enrichment via syngenetic precipitation or early diagenetic processes. This study integrates sampling, petrography, and in situ analysis of pyrite hosted by carbonate sequences to establish the trace element systematics of pyrites and their enrichment in critical metals. This Meso-Neoproterozoic-aged basin, having pyrites deposited in shallow marine conditions, is considered a prospect for hosting critical metals like Se, Mo, Co, and Ni that can be explored using nano-geoscience techniques.

The integration of advanced processing technologies with circular economy principles can enhance domestic availability of these critical elements, reducing reliance on imports and mitigating supply chain vulnerabilities. The findings demonstrate that underexplored carbonate-hosted systems, such as those in the Bhima Basin, offer strategic opportunities for developing critical mineral resources in India. By linking geological characterization with processing innovation and recycling strategies, this work contributes to a holistic framework for sustainable critical metal supply.

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## **Extraction of Rare Earth Metals from E-Waste Using Ionic Liquids(ILs)**

**Md Izhar Hussain, Aarti Kumari**

Indian Institute of Technology(ISM), Dhanbad, Jharkhand, 888122

### **Abstract:**

Potassium is considered as one of the basic plant nutrients for its healthy growth and development with no known substitute till date. More than 90% of potassium produced today is used for the production of fertilizer. India does not have any convention resource of potash therefore it is important to develop a process for extraction of potash from indigenous potassium containing silicate minerals. This work explores the possibility for extraction of potash from natural occurring tectosilicate K-feldspar mineral that contain large amount of potassium in crystal lattice. Detailed physico-chemical characterization of K-feldspar collected from Jaipur district, Rajasthan (India) was carried out by X-ray diffraction (XRD), Scanning electron microscopy (SEM) followed by Energy-dispersive X-ray (EDX), Inductively coupled plasma optical emission spectrometry (ICP-OES). The major matrix of feldspar sample was found to contain 64.75% SiO<sub>2</sub>, 18.65% Al<sub>2</sub>O<sub>3</sub>, 11.80% K<sub>2</sub>O and 2.53% Na<sub>2</sub>O. A combined pyro-hydro metallurgical route is studied to process the K-feldspar in order to recover potash fertilizer, silica powder and ferro-silicon simultaneously as final product. Different process parameters like charge composition, temperature and residence for smelting operation along with hydrometallurgical leaching reagent concentration, time and temperature were studied and optimized. The final product with purity of 99% KCl, 60% Fe-Si and 96% SiO<sub>2</sub> is produced.

Keywords: K-feldspar, smelting, leaching, potash fertilizer, ferro-silicon

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## **Kinetic Assessment of the Flotation Response of Low-Grade Critical Minerals' Copper**

**Abhishek Ranjan, Pankaj Kumar Jain**

Department of Fuel, Mineral & Metallurgical Engineering Indian Institute of Technology (ISM) Dhanbad

### **Abstract:**

This study investigates the froth flotation kinetics of low-grade copper ore from the Malanjkhand deposit, India. The ore, characterized by disseminated chalcopyrite in a quartz feldspathic host rock, required fine grinding for mineral liberation.

Batch flotation tests were conducted using Potassium Ethyl Xanthate (PEX) as a collector, Methyl Isobutyl Carbinol MIBC as a frother, and Carboxy Methyl Cellulose as a depressant. The results were evaluated using classical first-order kinetic models.

Collector and frother dosage significantly influenced the flotation rate and ultimate recovery. Kinetic analysis established that the process was best described by a first-order model with a fast-floating component. The maximum theoretical recovery ( $R_{\infty}$ ) was 93.37%, and the fast floating rate constant ( $k$ ) was  $0.024 \text{ s}^{-1}$ , confirming rapid initial capture of hydrophobic particles. The findings demonstrate the ore's amenability to froth flotation. The derived kinetic parameters provide a critical basis for optimizing reagent regimes and for the design and scale up of industrial flotation circuits for this ore type.

Keywords: Froth Flotation, Collector, Frother, Flotation Kinetics

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## **Advances in Beneficiation and Extraction Techniques for Sustainable Lithium Recovery: A Review**

**Suruchi Kumari, Shatrughan Soren**

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### **Abstract:**

The need for effective and sustainable recovery techniques has increased due to the growing demand for lithium and its crucial role in lithium-ion batteries, E-Vehicles, advanced electronics and renewable energy storages. Conventional lithium extraction from brines and hard rock deposits, faces challenges including high water and energy consumption, long processing times, and environmental impacts. Recent advances in beneficiation and extraction techniques are toward greater efficiency and sustainability. Improved mineral beneficiation strategies, such as sensor-based ore sorting, froth flotation, and selective grinding, enhance recovery from low-grade hard rock deposits and reducing waste generation. In brine processing, innovations in direct lithium extraction (DLE) using ion-exchange materials, solvent extraction, and membrane-based separations significantly reduce processing times and improve selectivity, minimizing chemical usage and land requirements.

This review highlights the latest advancements in integrated beneficiation and extraction techniques with renewable sources and circular economy approaches, contributing to a secure, environmental friendly, sustainable, and economically viable lithium supply.

Keywords: Lithium, Beneficiation, Extraction, Sustainable.

# Integrated experimental and simulation study of the effect of varying Al/Ta atomic ratio on the microstructure and mechanical properties in eutectic high entropy Alloy

**Manish Kumar Singh, Kesavan Ravi, Rahul M R**

Department of Fuel, Minerals and Metallurgical Engineering, Indian Institute of Technology (ISM) Dhanbad, 826004, India

## Abstract:

Designing and developing multicomponent alloys with balanced strength–ductility combinations is challenging. The multiphase alloys with soft matrix phase and hard phase reinforcement phases are promising to satisfy the property requirements. In the current study, we used a multiphase multicomponent alloy to further improve its properties by varying the composition and processing conditions. The reported eutectic high entropy alloy (EHEA) was taken, and Al was added to the matrix. The addition of Al to the EHEA is guided by the ThermoCalc calculation. The alloy was fabricated by a vacuum arc melting technique using pure elements. The current study focuses on the CALPHAD-guided alloy design approach for developing EHEA with cuboidal L12 precipitates in the ductile phase. The designed alloy exhibited a primary dendritic FCC phase and a eutectic colony of the FCC and Laves phases. The new alloy is subjected to a simulation-guided heat treatment cycle, resulting in a novel precipitation-strengthened microstructure. The current study confirms that the minute Al addition will modify the precipitation kinetics in the FCC phase and realise the formation of a unique microstructure in EHEAs. The prepared alloy was characterized using TEM, SEM, XRD and microhardness studies. The study proposes a novel EHEA system with a stable precipitation-strengthened FCC phase and an eutectic colony. From this integrated study, one could infer that the CALPHAD-guided design will accelerate the material design.

Keywords: EHEAs, CALPHAD, Precipitation, Heat Treatment, Alloy Design

# Critical Minerals and Energy Transition: A Comparative Study of Policy and Regulatory Frameworks Between India and Australia

**Pawanpreet Kaur, Sudheer Singh Verma**

Research Scholar, Department of South and Central Asian Studies School of International Studies, Central University of Punjab, Bathinda, Punjab, India and Assistant Professor, Department of South and Central Asian Studies School of International Studies, Central University of Punjab, Bathinda, Punjab, India

## Abstract:

In an age of energy transition, the critical minerals have emerged as the strategic fulcrum anchoring both climate ambitions and pathways to sustainable industrial future.

Their scarcity, uneven distribution, and indispensability to clean energy, digital infrastructure, advanced defence capabilities have transformed them into the very currency of global power in the 21st century. The geopolitical importance of critical minerals has prompted India and Australia to pursue policy measures to secure supply chains and ensuring strategic resilience. Both nations are at the forefront of the world's energy transition, where Australia supplies the critical minerals needed for low-carbon technologies and India is a fast-emerging renewable energy infrastructure market. The objective of this study is twofold: first, to examine a comparative analysis of India and Australia's regulatory and policy framework governing critical minerals and second, to assess how comparative insights can inform cooperative strategies resilient critical mineral supply chains. The study is grounded in Policy Learning Theory, which frames policymaking as a reflexive and iterative process through which governments refine policies by systematically observing, evaluating, and adapting the experiences of other actors. By adopting this lens, the research moves beyond mere description to identify strategies for improving regulatory coherence, sustainability outcomes and strengthening bilateral cooperation within critical mineral supply chains. Methodologically, the research employs Comparative Policy Analysis to provide a systematic foundation for assessing the policy objectives, tools and execution strategies employed by both nations. The analysis underscores the importance of harmonized policy and regulatory approaches in driving sustainable, resilient, and strategically aligned critical mineral supply chains between India and Australia.

Keywords: Critical Minerals, Energy Transition, Policy Framework, Supply Chain Resilience

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## **Efficient carbon dot green synthesis as a corrosion inhibitor for mild steel in an acidic environment**

**Pooja Kumari, Mahendra Yadav**

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Dhanbad, Jharkhand 826004, India

### **Abstract:**

Carbon dot CDLP and CDLT were synthesized by a step hydrothermal process. These carbon dots inhibited the mild steel (MS) corrosion process when dissolved in a 15 % HCl solution. They were water-soluble, low-cost, affordable, and environmentally friendly. The compound that contains a lone pair and  $\pi$ -electron, such as S, N, and O, as well as aromatic heterocyclic rings and other polar functional groups like nitrile(C=N), amine (NH), carbonyl(C=O), and thiol (SH), that are readily available for donation of electrons, act as good corrosion inhibitors for carbon dots for metal surfaces to inhibit the corrosion process. FTIR, UV-Vis, PL, XPS, and HRTEM analysis were used to characterize the synthesized CDLP and CDLT. The inhibitory efficiency of CDLP and CDLT was assessed using potentiodynamic polarization analysis, electrochemical impedance spectroscopy analysis, and weight loss measurement analysis.

By using FESEM, EDX, AFM, and XPS analysis, the surface morphology of the inhibited sample was examined, and the presence of a protective layer on the MS surface was verified. At 120 ppm concentration and 303K temperature, the inhibition efficiency of CDLP and CDLT was observed as 96.50 % and 90.21 % respectively, both from electrochemical impedance and weight loss analysis. The adsorption of CDLP and CDLT on the MS surface followed mixed adsorption (physisorption and chemisorption) and obeyed the Langmuir adsorption isotherm.

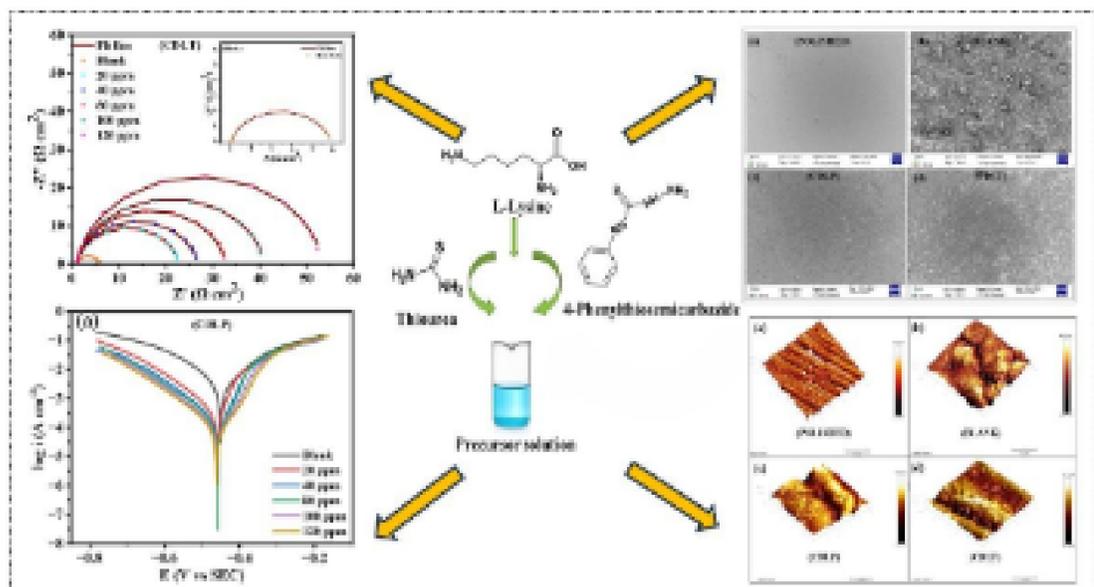


Figure 1: Graphical Abstract

Keywords: Electrochemical study, Corrosion inhibitor, 15 % HCl solution, carbon dots

## Ultrasonic Leaching for recovery of valuable metals from spent Lithium Ion Batteries (LIBs)

Rahul Ranjan, Ravi Kumar, Aarti Kumari

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### Abstract:

Lithium-ion batteries (LIBs) have emerged as the backbone of modern energy storage devices over the years, particularly due to their high energy density, fast charging, and long cycle life. With the continuous rise in the use of lithium-ion batteries (LIBs), a substantial amount of spent batteries is expected to accumulate in the near future. India currently lacks significant domestic lithium resources and relies heavily on imports. Waste batteries represent a significant secondary resource for critical metals such as lithium, cobalt, and nickel. With the rising consumption of LIBs, their end-of-life recycling holds immense potential for resource recovery. The extraction of critical metals from spent LIBs have been studied through pyrometallurgical (high-temperature smelting), hydrometallurgical (acid/alkali leaching), and direct recycling (reconditioning of cathode materials) methods. Hydrometallurgical processes are the most studied technique for the metal recovery from waste LIBs. However, the process often requires longer roasting times and higher chemical consumption. In the present investigation, the ultrasonic leaching study has been carried out for the recovery of valuable metals from spent LIBs.

The manual dismantling have been done to recover cathode active materials (CAMs) from the spent batteries and leaching have been performed under ultrasonication for metal recovery. The application of ultrasonic waves generates acoustic cavitation, which enhances mass transfer, reduces particle size, and accelerates reaction kinetics. This approach is expected to significantly improve the recovery efficiency of lithium and cobalt while minimizing reagent usage and processing time, making it a more sustainable alternative to conventional leaching.



Fig. 1 Manual dismantling of spent LIBs for obtaining cathode active material (CAMs) for metal recovery

## A recent development for recovery of Niobium and Tantalum from primary resources: A review

Ravi kumar, S. Shekhar, S. Sinha, K. Kumar

CSIR-National Metallurgical Laboratory, Jamshedpur-831007, India

### Abstract:

Niobium (Nb) and tantalum (Ta) have become incredibly important to a broad variety of industries, going from the automobile, aerospace, construction sectors, defence, nuclear, electronic, and chemical companies. Due to their unparalleled properties, their monopolistic and sometimes volatile markets, as well as the absence of cost-effective alternatives, Nb and Ta are often labelled as “critical” or “strategic raw materials. The growing demand for miniaturized electronic devices and sustainable energy systems continues to drive the global importance of these metals. The extraction of niobium and tantalum primarily involves the processing of mineral ores such as columbite-tantalite (coltan), pyrochlore, and microlite etc. The process begins with ore concentration through physical methods like gravity separation, followed by chemical treatment involving leaching with hydrofluoric acid and solvent extraction techniques to separate the two metals. Due to their chemical similarity, the separation is challenging and requires careful control of process parameters. In context, this article aims to analyse and evaluate the challenges and advances in the efficient extraction of niobium and tantalum, focusing specifically on the review of pyro -hydrometallurgical processes from primary resources.

Keywords: Niobium, Tantalum, roasting, leaching

# A comprehensive review on "Techno-economic evaluation and process enhancement for the recovery of Neodymium from Hard disk Drive (HDD)"

Madhumita Patel, P. Saravanan, Digvijay Kumar

Department Of Environmental Science and Engineering, IIT (ISM) Dhanbad

## Abstract:

Rapid technological advancements and consumer demand for the newest gadgets are the primary contributors of the growing global issue of e-waste generation. Primary sources of rare earth elements (REEs) are depleting drastically due to their excessive utilization in modern world e-gadgets. Recovery of such elements from secondary sources is highly needed. REEs play a vital role in digitalization and industrialisation. This review comprehensively focused on extraction of Neodymium from HDD by using Hydrometallurgy and Pyrometallurgy process. The advantages and limitations of these processes have been critically examined. High-temperature pyrometallurgical processes recover rare earths as alloys or mixed compounds, which needs further purification. Hydrometallurgical process faces drawbacks such as high chemical consumption and substantial rare earth losses through leaching during purification. This highlights the need for developing a robust, eco-friendly, and energy-efficient process for the selective extraction and separation of REEs from HDD containing NdFeB magnets.

Keywords: REE, HDD, Techno- Economic, leaching, sustainable.

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## Effect of Cu Addition on the Microstructure and Transformation Characteristics of New TiNiCuZr High Entropy Shape Memory Alloy

Shruti Diwase and Rahul M. R.

Department of Fuel, Minerals and Metallurgical Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Jharkhand, India

## Abstract:

TiNiCuZr-based shape memory alloys (SMAs) exhibit promising multifunctional properties for applications in actuators, sensors, and energy-efficient devices, owing to their excellent shape memory effect and mechanical properties. Precise control of the transformation temperature is crucial to tailor these alloys for specific operating environments. This study investigates the effect of copper addition on the phase transformation temperatures of TiNiCuZr SMAs. Alloys with varying copper contents were synthesized using arc melting followed by Characterization. Differential scanning calorimetry (DSC) analysis revealed systematic shifts in the martensitic transformation start ( $M_s$ ) and finish ( $M_f$ ) temperatures.

Characterization using X-ray diffraction (XRD) and scanning electron microscopy (SEM) provided insights into phase and microstructural characteristics. Mechanical characterization showed typical shape memory effect with martensite detwinning. These findings contribute to the development of critical metal-based high-performance materials for sustainable technologies.

Keywords: Shape memory alloys, multifunctional properties, high strength, mechanical characterization.

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## **Green Hydrometallurgical Leaching of Metals from Waste Printed Circuit Boards using Deep Eutectic Solvents**

**Ziaul Haque**

Department of Fuel, Minerals and Metallurgical Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Jharkhand, India

### **Abstract:**

Conventional metal recycling methods involve intensive energy consumption and environmental pollution, which suggests the need for a changeover to eco-friendly solvent alternatives. Deep eutectic solvents (DES) are a suitable alternative since they are less harmful and have a simple production procedure. In this research, we tested various DESs and established that carboxylic acid-based DESs are efficient leaching agents for copper (Cu) and silver (Ag) recovery from waste printed circuit boards (PCBs) when combined with H<sub>2</sub>O<sub>2</sub>. Copper leaching was also effective at diluted levels, with recoveries greater than 80% and 60% at 1:2 and 1:4 DES-to-water ratios, respectively. Lactic acid-based DES (Lac-DES) was also more selective for copper than silver, while the oxalic acid-based DES (Ox-DES) surprisingly showed selective leaching of up to 40% of silver. These results are reflective of the potential of specially engineered DES systems in meeting the rising demand for metals recovered from electronic waste.

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## **Selective separation of trivalent rare earth elements from divalent metal ions in compact fluorescent leach liquor using novel phosphonic resin**

**Vinita Kumari\*, Ritesh Ruhela**

Materials Processing Division, Bhabha Atomic Research Centre, Mumbai, India-400085  
Homi Bhabha National Institute, Mumbai, India-400094

### **Abstract:**

The growing demand for rare earth elements (REEs) has generated significant interest in their recovery from various end-of-life products due to economic and environmental benefits. Yttrium, a rare earth element, is widely used in advanced functional materials owing to its remarkable fluorescent, magnetic, optical, and catalytic properties.

REEs, in general, are crucial to the development of green technologies and are in high demand across a wide range of applications. Conventional techniques such as precipitation, solvent extraction, ion exchange, and extraction chromatography have been extensively studied for REE recovery. In the present work, the separation of yttrium from strontium (a trivalent–divalent ion separation) was explored using solid–liquid extraction through a batch methodology on a grafted mono-phosphonate resin. The grafted functional groups were confirmed using FT-IR spectroscopy of the resin beads. The optimum condition for separation was achieved in 0.25 M nitric acid medium, where the uptake of strontium was minimal.

Keywords: Phosphonic resin, Yttrium (III), Strontium (II), REE

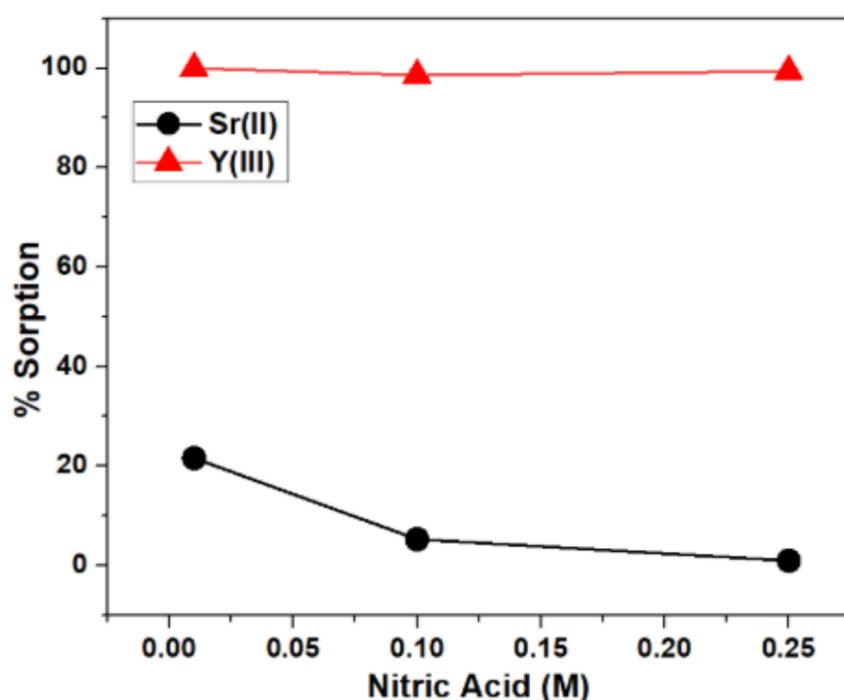


Figure 1: Percentage sorption of Y(III) and Sr(II) as a function of nitric acid concentration.

## An efficient process for the production of potash fertilizer and ferro-silicon from indigenous K-feldspar

Shabnam Ara, S. Shekhar, S. Sinha, D. Mishra, K.K Sahu

Metal Extraction and Recycling Division and CSIR- NML Metallurgical Laboratory Jamshedpur - 831007

### Abstract:

Potassium is considered as one of the basic plant nutrients for its healthy growth and development with no known substitute till date. More than 90% of potassium produced today is used for the production of fertilizer. India does not have any convention resource of potash therefore it is important to develop a process for extraction of potash from indigenous potassium containing silicate minerals. This work explores the possibility for extraction of potash from natural occurring tectosilicate K-feldspar mineral that contain large amount of potassium in crystal lattice. Detailed physico-chemical characterization of K-feldspar collected from Jaipur district, Rajasthan (India) was carried out by X-ray diffraction (XRD), Scanning electron microscopy (SEM) followed by Energy-dispersive X-ray (EDX), Inductively coupled plasma optical emission spectrometry (ICP-OES). The major matrix of feldspar sample was found to contain 64.75% SiO<sub>2</sub>, 18.65% Al<sub>2</sub>O<sub>3</sub>, 11.80% K<sub>2</sub>O and 2.53% Na<sub>2</sub>O.

A combined pry-hydro metallurgical route is studied to process the K-feldspar in order to recover potash fertilizer, silica powder and ferro-silicon simultaneously as final product. Different process parameters like charge composition, temperature and residence for smelting operation along with hydrometallurgical leaching reagent concentration, time and temperature were studied and optimized. The final product with purity of 99% KCl, 60% Fe-Si and 96% SiO<sub>2</sub> is produced.

Keywords: K-feldspar, smelting, leaching, potash fertilizer, ferro-silicon

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## **Critical Metals for a Sustainable Future: Opportunities and Strategies for India**

**Saket Kumar, Sujit Rajak, Saurabh Kumar, Sumit Prakash, Maneesh Vishvakarma, Ashish Kumar Vishwakarma, Vivek Kumar Himanshu**

CSIR-Central Institute of Mining and Fuel Research, Dhanbad-826001, India ; Indian Institute of Technology (Indian School of Mines); and National Institute of Technology, Raipur

### **Abstract:**

The global transition towards clean energy and digital infrastructure has elevated critical metals such as lithium, cobalt, rare earth elements (REEs), and nickel to strategic importance. India, with its growing resource base and industrial demand, stands at a pivotal juncture to establish a sustainable and self-reliant critical metals ecosystem. This paper presents a comprehensive review of the current landscape of critical metal exploration, extraction, and processing in India, with special emphasis on emerging opportunities and bottlenecks in mining and metallurgical practices.

The review covers key mineral occurrences across the country, recent technological advancements in geophysical prospecting, beneficiation strategies for low-grade ores, and hydrometallurgical separation techniques tailored for Indian conditions. Furthermore, the paper discusses the role of artificial intelligence and automation in resource modelling and extraction optimization. National initiatives such as the National Critical Minerals Mission and reforms in regulatory frameworks are critically evaluated to understand their effectiveness in fostering a resilient supply chain.

By integrating geological, technological, environmental, and policy dimensions, this review identifies strategic gaps and outlines a roadmap for accelerating India's transition towards a secure and sustainable critical metals value chain. The findings are relevant to researchers, policymakers, industry leaders, and sustainability experts working at the intersection of resource security and clean technology.

Keywords: Critical metals, exploration, beneficiation, sustainable mining

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# Strategic Assessment of Rare Earth Element Potential from Godavari Valley Coalfield, India

**Amit Kumar Parida, Amit Karmakar, P. Gopinathan, Reginald Ebhin Masto**

CSIR-Central Institute of Mining and Fuel Research, Dhanbad, Jharkhand, 828108, India; and Academy of Scientific and Innovative Research, Ghaziabad, Uttar Pradesh 201002, India

## Abstract:

Rare Earth Elements (REEs), also known as critical minerals, play an essential role in powering modern technology, including smartphones, computers, and electric vehicles. They are also indispensable components in renewable energy systems, such as wind turbines and solar panels, due to their unique magnetic and conductive properties. However, the global supply of REEs is currently constrained by the limited number of viable primary sources, most of which are concentrated in a few countries. This creates significant vulnerabilities in international supply chains and raises concerns about potential shortages. Consequently, there is a growing emphasis on finding alternative resources, such as recycling and extraction from secondary sources, to ensure a stable and sustainable supply. The worldwide research has been focused on coal beds that may have potential recovery of REE or REY. Although India has significant coal reserves, the geochemistry of rare earth elements (REE) within its coalfields is still largely unexplored, with research limited to only a few basins. This study evaluates the REE potential of coal ash from six mines within the Pranhita-Godavari Valley Coalfield, India: Kakatiya, SCCL OCP, JVR, Manuguru, GDK, and Goleti, using laboratory-based ashing and digestion following ASTM D6357 protocols. Analyses of major, trace, and rare earth element concentrations were conducted to enable companies to show direct interest in specific mines for REE/REY extraction. The results reveal significant REE concentrations across all sites, with notable enrichments in elements such as Cerium (Ce), Neodymium (Nd), and Yttrium (Y). Among the mines, JVR (70.6 ppm Ce, 32.9 ppm Nd) and Manguru (71.0 ppm Ce, 29.30 ppm Nd) show particularly high REE values, while SCCL OCP and GDK shows higher Strontium (Sr) and Zirconium (Zr) levels. These findings emphasize the potential of Godavari Valley Coalfield coal ash as a viable secondary source of REEs, supporting India's strategic mineral security and clean energy transition.

Keywords: Rare Earth Elements, Critical Minerals, Coal Ash, Godavari Valley Coalfield, Resource Recovery

# An AI-Driven Framework for Predictive Mapping and Efficient Extraction of Critical Metals from Indian Mining Sites

**Amna Anand, Yash Vardhan, Sonal, Rajesh Kumar**

Birla Institute of Technology, Mesra, Off-campus Deoghar Jharkhand, India; and Birla Institute of Technology, Mesra, Ranchi Jharkhand, India

## **Abstract:**

Growing strategic value of critical metals in clean energy technologies and defense systems requires creative strategies for exploration and extraction. This research suggests the concept of designing an AI-based system for predictive mapping and effective extraction of critical metals from primary and secondary sources. The research is concentrated on combining machine learning models with geospatial information, remote sensing images, and mineral databases to locate prospective critical mineral areas in unexploited and post-industrial mining fields. One of the most important components of the framework is applying image processing and convolutional neural networks (CNN) to extract features from automated hyperspectral and multispectral satellite imagery to identify surface alteration signatures that reflect the presence of critical metals. Concurrently, unsupervised learning algorithms will be applied to cluster and classify geochemical and geophysical datasets for anomaly detection. On the extraction side, we intend to mimic the deployment of sensor-based ore sorting models and AI-driven decision systems for optimizing processes, specifically in hard-to-handle polymetallic ores. The framework will be tested against case studies of Indian mining locations with documented reserves of rare earth elements (REEs), lithium, and cobalt. The proposed methodology seeks to minimize exploration expenditure, increase targeting efficacy, and optimize resource recovery while meeting environmental sustainability objectives. The project also addresses issues of model interpretability, heterogeneity of data, and integration with current mining operations. The findings are anticipated to inform national critical mineral policies and create a basis for smart, low-footprint mining in India.

Keywords: Critical metals, predictive mapping, machine learning, image processing, ore sorting, sustainable mining

---

## **Extraction of Critical Minerals from spent Lithium-Ion Batteries**

**Eshan Pethkar and Luckman Muhmood**

Undergraduate student and Professor, Department of Mechanical Engineering, KJ Somaiya School of Engineering, Somaiya Vidyavihar University, Mumbai

## **Abstract:**

Electric Vehicles play a critical role in reducing CO<sub>2</sub> emissions when used in the automobile sector. Lithium, along with Cobalt, is declared critical mineral for India. Hence, there needs to be a significant focus on its extraction after the end of life of a Lithium-ion Battery (LIB). This work focuses on a combinatory technique by using hydrometallurgy as well as pyrometallurgy to realize this.

Spent LIBs are discharged chemically and later opened up for further recovery of Lithium and Cobalt. The black mass on the foil was scraped, and X-ray Diffraction studies on this powder showed that the battery cathode was Lithium Cobalt oxide. The cathode side (black mass containing the Lithium and Cobalt, along with Aluminium foil) is first reacted with 10% NaOH to dissolve the Aluminium foil. The resultant mixture was observed to have a bluish colour. The black mass was filtered out while the remaining liquid was evaporated to obtain the salt. The salt was observed to be highly hygroscopic in nature. Its phase studies are underway.

Thermogravimetry studies of the cathode black mass will be carried out to find the suitable temperatures and holding time for the pyrometallurgical conversion to obtain the Cobalt precursor.

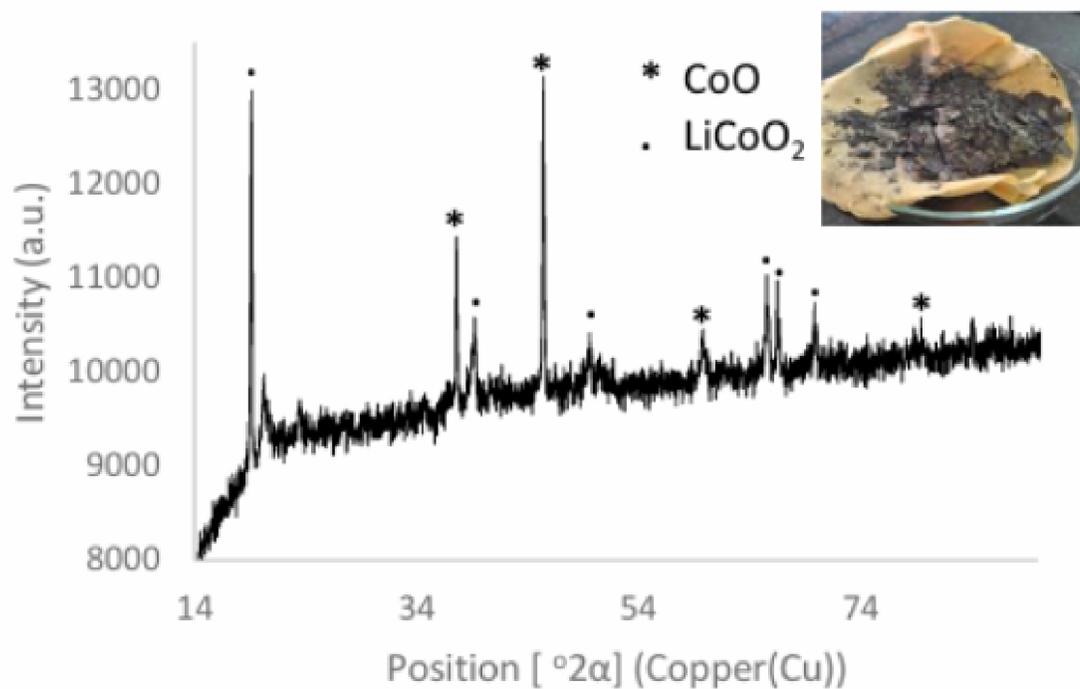


Figure 1: XRD graph of extracted black mass

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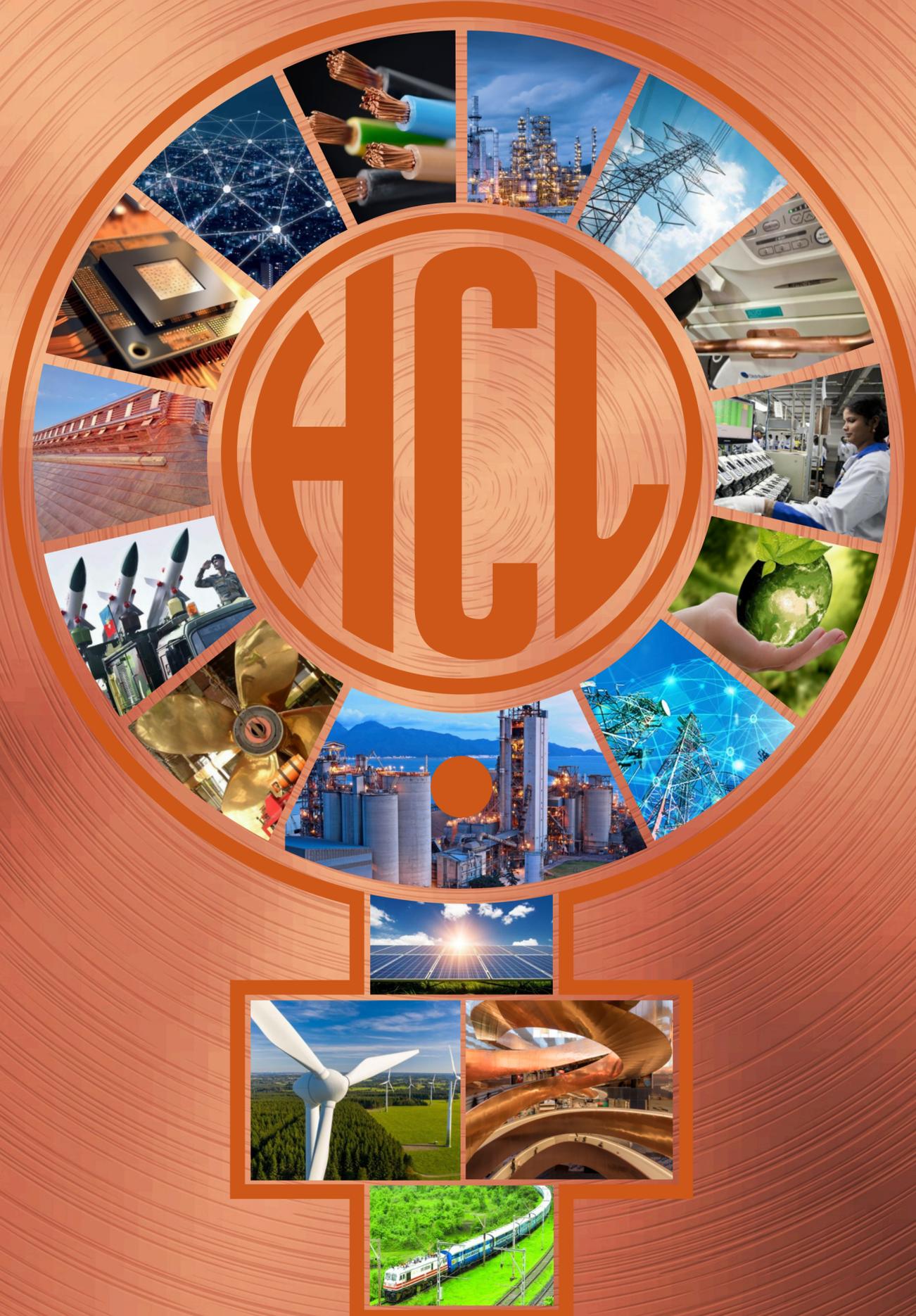


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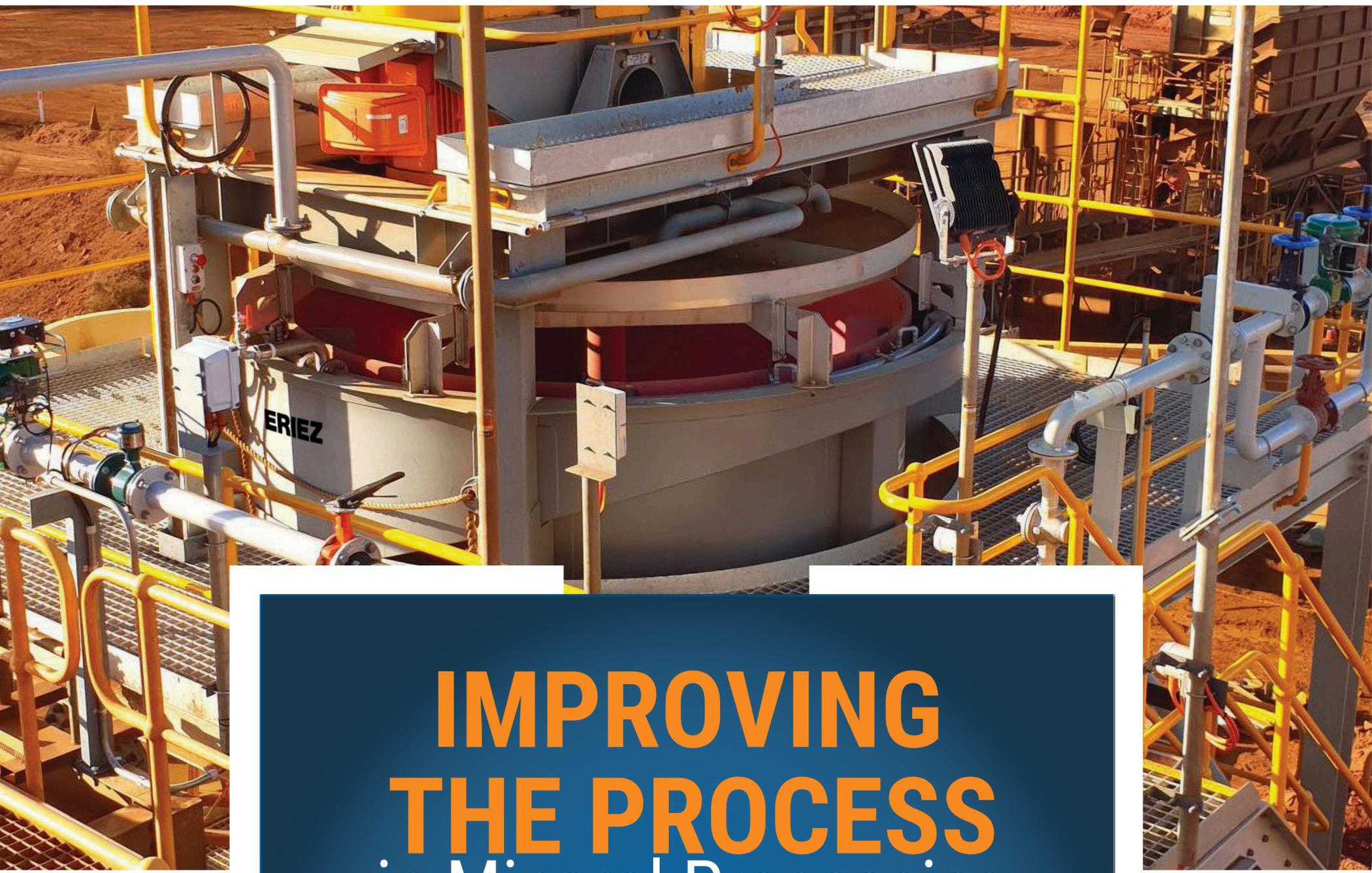
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