



**NATIONAL CONFERENCE
ON**

CRITICAL METALS:

Advancements in Extraction & Recycling Technologies

NACCRIM – 2026



25–26 September 2026



**Kalidas Auditorium
IIT Kharagpur**

Organized by

**DRDO Industry Academia - Centre of Excellence (DIA-CoE)
IIT Kharagpur**



<https://diacoekgp.iitkgp.ac.in/>



Dr. Samir V. Kamat

Secretary (Retd.), Dept. of Defence (R&D) &
Chairman (Retd.), DRDO

It is a pleasure to know that the DRDO Industry Academia Centre of Excellence (DIA-CoE), IIT Kharagpur is organizing the National Conference on "Critical Metals: Advancements in Extraction and Recycling Technologies". I extend my compliments to the organizers for selecting a theme that is of profound strategic significance to India's technological future and defence preparedness.

Critical metals such as rare earth elements, Li, Ni, Co, W etc. have emerged as indispensable enablers of modern technologies that underpin national security, economic resilience and industrial competitiveness. From aerospace and naval systems to advanced electronics, energy storage, sensors and next-generation manufacturing, the performance of critical defence and strategic systems increasingly depends on assured access to these materials. As global supply chains become more vulnerable to geopolitical disruptions and resource concentration, developing indigenous capabilities across the entire value chain—from resource characterization and extraction to advanced processing, recycling and circular utilization—has become a national imperative. Technological leadership in this domain will be a decisive factor in achieving strategic autonomy and sustaining India's journey towards Aatmanirbhar Bharat.

Addressing such complex challenges requires close integration of scientific excellence, engineering innovation and translational research. The DRDO Industry Academia Centres of Excellence (DIA-CoEs) were established with this very objective—to create enduring partnerships between DRDO and premier academic institutions for developing futuristic technologies of strategic importance. By bringing together the research strengths of IIT Kharagpur, the application-driven perspective of DRDO and the innovation capabilities of industry, the DIA-CoEs provide a unique ecosystem for advancing technologies related to critical metals. I am confident that the deliberations during this conference will stimulate new research directions, strengthen collaborative networks and accelerate the development of indigenous technologies that will contribute to India's strategic material security.

I congratulate the Director and the entire team of DIA-CoE, IIT Kharagpur for this timely initiative. I am sure the conference will serve as an important platform for scientific exchange and collaborative innovation, and I extend my best wishes for its grand success.



Prof. Suman Chakraborty

Director, IIT Kharagpur

It gives me immense pleasure to know that the DRDO Industry Academia Centre of Excellence (DIA-CoE), IIT Kharagpur is organizing the National Conference on “Critical Metals: Advancements in Extraction and Recycling Technologies.” I congratulate the organizers for initiating a national dialogue on a subject that lies at the very heart of India's technological sovereignty, industrial competitiveness, and strategic resilience.

The twenty-first century will increasingly be defined not by access to conventional resources, but by mastery over critical materials that power semiconductors, quantum technologies, aerospace systems, clean energy, electric mobility, advanced manufacturing, strategic defence, and intelligent infrastructure. Critical metals have therefore emerged as strategic assets that determine a nation's technological capability, economic security, and geopolitical influence.

For Bharat, the challenge extends well beyond discovering new mineral resources. It demands the creation of an integrated innovation ecosystem encompassing advanced extraction technologies, intelligent mineral processing, sustainable metallurgy, urban mining, circular material flows, AI-driven process optimization, predictive resource analytics, and high-value recycling. The nations that lead these technologies will shape the industries of tomorrow.

This transformation cannot be achieved through isolated scientific advances alone. It requires convergence across disciplines—materials science, metallurgy, mining engineering, chemical engineering, environmental sciences, computational intelligence, robotics, automation, and systems engineering—supported by strong partnerships among academia, national laboratories, industry, start-ups, and government. The future belongs to ecosystems where discovery seamlessly translates into deployable technologies, indigenous manufacturing capabilities, and globally competitive enterprises.

At IIT Kharagpur, we believe that research achieves its highest purpose when it simultaneously advances scientific frontiers and strengthens national capability. The DRDO Industry Academia Centres of Excellence embody precisely this philosophy by creating a unique platform where frontier science, strategic technologies, industrial innovation, and national priorities converge. These Centres are not merely research collaborations; they are engines for building indigenous technologies, nurturing future scientific leaders, accelerating technology readiness, and advancing the vision of Aatmanirbhar Bharat through deep technological innovation.

I am confident that this conference will stimulate transformative scientific discussions, catalyse new interdisciplinary collaborations, and inspire bold research directions that redefine how India approaches the extraction, processing, recycling, and sustainable utilization of critical metals. More importantly, I hope it will help build a national innovation ecosystem capable of transforming critical material security into a strategic technological advantage for the country.

I compliment the Director, the DIA-CoE leadership, and the entire organizing team for convening this timely and significant conference. I wish the conference every success and look forward to the Centre continuing to serve as a national catalyst for disruptive research, translational innovation, and strategic partnerships that position India among the world's leaders in advanced materials and critical resource technologies.



Dr. Anupam Sharma

Distinguished Scientist & Director General
(Technology Management), DRDO

I congratulate the DIA-CoE at IIT Kharagpur on organizing the National Conference on "Critical Metals: Advancements in Extraction & Recycling Technologies." In today's global landscape, a country's technological sovereignty is closely tied to its material security. For India to build a truly self-reliant defense ecosystem, we must establish reliable, domestic supply chains for strategic minerals. This conference addresses a major national priority, highlighting the critical role that advanced metallurgy plays in supporting our next-generation defense platforms.

As the head of Technology Management at DRDO, my focus is on channelling research grants toward projects that bridge the gap between academic innovation and defense readiness. While extraction and recycling are specialized fields, their strategic value is clear to anyone looking at the bigger picture of national security. Through targeted R&D funding, DRDO is committed to supporting academic partners as they take on high-stakes engineering challenges. The research vertical on "Advanced Extractive Metallurgy and Recycling Technologies" at DIA-CoE IIT Kharagpur is a prime example of how we can work together to turn laboratory breakthroughs into scalable, real-world technologies.

Bringing together experts from government laboratories, academia, and private industry is exactly what we need to build a comprehensive roadmap for India's material independence. I also encourage the participating students and young scholars to fully immerse themselves in these defense-aligned research opportunities. I commend the leadership and organizing team at DIA-CoE IIT Kharagpur for taking the initiative to host this essential event, and I wish all the delegates a highly productive and successful conference.



Dr. R. Balamuralikrishnan

Distinguished Scientist & Director General (Naval Sciences & Materials), DRDO

It gives me great pleasure to know that the DRDO Industry Academia Centre of Excellence (DIA-CoE), IIT Kharagpur is organizing the National Conference on "Critical Metals: Advancements in Extraction and Recycling Technologies." I congratulate the Director and the organizing team for bringing together researchers, scientists, technologists and industry experts to deliberate on a subject that is rapidly emerging as a cornerstone of technological capability, industrial resilience and national security.

Advanced materials lie at the heart of every modern defence platform. Whether in aerospace propulsion, naval systems, armoured vehicles, missiles, electronics or energy systems, the performance and reliability of these technologies are intrinsically linked to the availability of high-quality strategic materials. Many of these materials depend on critical metals and alloys whose supply chains are increasingly constrained by limited natural resources, complex processing routes and evolving geopolitical realities. Consequently, sustainable extraction, efficient processing, recycling and life-cycle management of critical materials have become essential components of India's quest for technological self-reliance.

As DRDO's premier laboratory for the development of metallic materials, alloys, ceramics, composites and advanced materials processing technologies, the Defence Metallurgical Research Laboratory (DMRL) has consistently worked towards developing indigenous materials solutions for strategic defence applications. In recent years, recycling and value recovery of critical metals and strategic alloys—including tungsten and nickel-based superalloys—have assumed increasing importance as part of a broader effort to enhance resource efficiency, reduce import dependence and support a circular materials economy for defence. Addressing these challenges requires close collaboration among research laboratories, academic institutions and industry, combining scientific innovation with engineering excellence to develop scalable and deployable technologies.

The DRDO Industry Academia Centres of Excellence provide an important mechanism for fostering such collaborations. By leveraging the complementary strengths of IIT Kharagpur, DRDO laboratories and industrial partners, these Centres can accelerate the development of advanced extraction, processing and recycling technologies that address both strategic and civilian needs. I am confident that this conference will promote meaningful scientific exchange, inspire new collaborative research initiatives and contribute significantly to strengthening India's capabilities in the critical materials domain.

I compliment the DIA-CoE, IIT Kharagpur for this timely initiative and extend my best wishes for the success of the conference. I am sure that the deliberations and interactions during this conference will pave the way for impactful research partnerships and innovative technological solutions that will benefit both the defence sector and the nation at large.



Dr. N. Ranjana

Outstanding Scientist & Director, DFTM, DRDO

It gives me immense pleasure to congratulate the DRDO Industry Academia–Centre of Excellence (DIA-CoE) at IIT Kharagpur for organizing the National Conference on “Critical Metals: Advancements in Extraction & Recycling Technologies”.

From the perspective of DRDO/defence, securing robust, sovereign supply chains for critical minerals is not just a technological challenge, but a strategic necessity. As global geopolitical dynamics shift, India's defense preparedness hinges on our ability to indigenously process, extract, and recycle these crucial materials. This conference addresses a vital national priority, and its theme perfectly aligns with the core research mandate of DFTM to foster self-reliance in strategic technologies.

At DFTM, our policy-level vision aims at actively steering the DIA-CoEs to serve as conduits between premier academic institutions and the defense ecosystem. We strongly encourage faculty members to transition from purely fundamental research toward high Technology Readiness Level (TRL) projects with an objective to develop functional prototypes, advanced materials, and scalable processes/systems that can transition directly from laboratory floors to production environment. By focusing on the dedicated research vertical of “Advanced Extractive Metallurgy and Recycling Technologies”, DIA-CoE IIT Kharagpur is uniquely positioned to bridge this gap and supply the next generation of materials required by our armed forces.

Furthermore, a critical dimension of our mandate is to cultivate the future workforce of Indian defense R&D. I strongly urge the participating students and research scholars to actively engage with DRDO-funded projects through sponsored internships and hackathons. Your fresh perspectives are vital to solving complex technological puzzles.

I commend the leadership and organizing team at DIA-CoE IIT Kharagpur for providing this timely platform. I wish all the delegates and participants a highly successful, collaborative, and impactful conference.



Message

Dr. Dipak Kumar Das

Outstanding Scientist (Retd.), DMRL, Hyderabad &
Director, DIA-CoE IIT Kharagpur

The growing importance of critical metals has brought materials science and extractive metallurgy to the forefront of strategic technologies. These materials are indispensable for advanced defence systems, aerospace, electronics, clean energy, electric mobility and several other high-technology sectors. At the same time, increasing global demand, supply chain uncertainties and limited natural resources have made it essential to develop indigenous capabilities in extraction, processing, recycling and resource recovery. The National Conference on "Critical Metals: Advancements in Extraction and Recycling Technologies" has been conceived with this objective—to provide a common platform for researchers, scientists, industry and policymakers to discuss emerging challenges and explore innovative technological solutions.

The DRDO Industry Academia Centres of Excellence were established with the vision of harnessing the research strengths of premier academic institutions to address future defence technology requirements. The DIA-CoE at IIT Kharagpur is committed to strengthening this partnership by promoting collaborative and multidisciplinary research in areas of strategic importance. IIT Kharagpur has a strong foundation in metallurgy and materials engineering, with active research in extractive metallurgy, critical and rare earth metal recycling, advanced materials and allied disciplines. Over the years, many faculty members of the Institute have made significant contributions through DRDO-sponsored research projects, reflecting the enduring partnership between IIT Kharagpur and DRDO in advancing technologies of national importance.

For me, this conference has a special significance. As an alumnus of the Department of Metallurgical and Materials Engineering at IIT Kharagpur and having spent my professional career at the Defence Metallurgical Research Laboratory (DMRL), Hyderabad, I have witnessed the vital role that advanced materials play in strengthening our nation's technological capabilities. It is therefore a matter of great satisfaction to see my alma mater and DRDO working together through the DIA-CoE to address an area of growing strategic importance.

I am confident that this conference will promote meaningful interactions among researchers from academia, DRDO laboratories and industry, leading to new ideas, stronger collaborations and innovative technologies in the field of critical metals. I hope the deliberations during the conference will contribute to India's vision of technological self-reliance in this area.

I congratulate all those who have contributed to the organization of this conference, including the DIA-CoE team at IIT Kharagpur, and extend my best wishes for its success.



Message

Dr. G. Balachandran

Scientist (Retd.), DMRL, Hyderabad
Former Chief Technology Officer, Kalyani
Carpenter, Special Steels Ltd.
Head R&D (Retd.), JSW Steel Ltd.
Proprietor, Expert Metal Consulting, Coimbatore

I congratulate the DIA-CoE at IIT Kharagpur on organizing this timely National Conference on “Critical Metals: Advancements in Extraction & Recycling Technologies.” Having spent half my career working with DRDO followed by equally long career leading industrial R&D at Ashok Leyland, Kalyani Group and the JSW Steel Group, I have learnt first-hand how material security drives both national defense and industrial growth. Securing critical metals such as nickel and Rare Earths is no longer managing a supply chain issue—it is a vital part of India’s technological independence. Both the public and the private sectors are venturing into the relevant technologies from exploration, extraction, recycling, and application development within the country.

Developing reliable extraction technologies for these strategic metals requires a strong link between the laboratory science and real-world industrial operations. Moving a metallurgical process from a small laboratory to a commercial plant is a complex journey. To bridge this gap successfully, India needs focused platforms exactly like the DIA-CoE at IIT Kharagpur, where academic research is intentionally directed toward solving high-stakes practical engineering challenges.

I am particularly excited to connect with the young metallurgical engineers, researchers, and students attending this event. The future of India’s material self-reliance rests on their ability to innovate and optimize these extraction processes. I thank the organizing committee for inviting me to deliver a Keynote Lecture and for creating this essential space for the defense, academic, and industrial sectors to collaborate. I wish the conference great success.



Mr. B. K. Soni

Chairman & MD

Eco Recycling Limited (ECORECO), Mumbai

It is a great pleasure to congratulate the DIA-CoE at IIT Kharagpur on organizing this National Conference on "Critical Metals: Advancements in Extraction & Recycling Technologies." As India works toward technological self-reliance, building a smart, viable circular economy for critical minerals is incredibly important. Urban mining—recycling electronic and industrial waste—gives us an immediate way to secure our raw materials and protect ourselves from global market shifts.

At Eco Recycling Limited, we focus on creating sustainable, practical recycling solutions to recover valuable materials from end-of-life products. However, turning recycling into a massive, strategic national asset requires serious scientific backing. This is why partnerships between private industries and research hubs like the DIA-CoEs are so critical. By pairing industry experience with academic research, we can develop clean, high-yield metallurgical technologies that scale up successfully.

I am especially glad to learn that many young researchers and students would be participating in the conference. The future of India's material security is in their hands. I want to thank the organizing committee for inviting me to deliver the Keynote Address and for creating this valuable space for industry and academia to connect. I wish the conference great success.

25 September 2026		
08:30 - 09:30 AM	Registration	
Inaugural Session		
09:00 - 09:10 AM	Inaugural Session: Lighting of Lamps by Dignitaries	
09:10 - 09:20 AM	Address by the Dignitaries	Convenor: Dr. Dipak K. Das, Outstanding Scientist (Retd.) DMRL, Hyderabad & Director, DIA-CoE IIT Kharagpur
09:20 - 09:30 AM		Distinguished Guest: Dr. N. Ranjana, Outstanding Scientist and Director, DFTM, DRDO
09:30 - 09:40 AM		Distinguished Guest: Prof. Surjya Kanta Pal, Dean, Research and Development (R&D), IIT Kharagpur
09:40 - 09:50 AM		Distinguished Guest: Dr. R. Balamuralikrishnan, Distinguished Scientist & Director General (NS&M), DRDO
09:50 - 10:05 AM		Guest of Honour: Prof. Suman Chakraborty, Director, IIT Kharagpur
10:05 - 10:20 AM		Chief Guest: Dr. Samir V. Kamat, Secretary (Retd.), Department of Defence (R&D) & Chairman (Retd.), DRDO
10:20 - 10:45 AM	Tea Break	
Technical Session 1		
(Session Chair: Dr. G. Balachandran, Chairman, AMMRT Vertical of DIA-CoE IIT Kharagpur)		
10:45 - 11:20 AM	Keynote Lecture: Mr. B K Soni, Chairman & MD, ECO Recycling Limited Title: Urban Mining: India's Fastest Route to Critical Mineral Security	
11:20 - 11:45 AM	Invited Lecture: Dr. Abhishek Mukherjee, Head, Pyrometallurgy and Metallurgical Thermodynamics Section, Materials Processing Division, Associate Professor, Bhabha Atomic Research Centre (BARC), Mumbai Title: Advanced Extraction Technologies for Critical Metals: Challenges and Opportunities	
11:45 AM - 12:10 PM	Invited Lecture: Dr. S. S. Kalyan Kamal, Scientist- G, DMRL Title: Recycling of Critical Metals as a strategic way forward for sustainable Growth: A case study of Tungsten	
12:10 - 12:35 PM	Invited Lecture: Dr. Raj Kumar Dishwar, Assistant Professor, IIT Dhanbad Title: Recovery of high-grade cobalt oxide from zinc plant residue (ZPR) generated at zinc processing plants	
12:35 - 01:00 PM	Invited Lecture: Dr. Shivendra Sinha, Scientist-E, CSIR-National Metallurgical Laboratory, Jamshedpur Title: Interventions by CSIR-NML towards Critical metal recycling technologies: Bench Scale to Pilot Scale	
01:00 - 01:15 PM	Contributed Talk: Dr. Mouli Das Dawn, Postdoctoral Fellow, IIT Kharagpur Title: Beyond Frameworks: Engineering Metal–Organic Materials for Emerging Energy Technologies	
01:15 - 02:15 PM	Lunch Break	

Technical Session 2 (Session Chair: Dr. Kalyan Kamal, Scientist G, DMRL, Hyderabad)	
02:15 - 02:50 PM	Keynote Lecture: Dr. G. Balachandran, Scientist (Retd.), DMRL, Hyderabad; Former Chief Technology Officer, Kalyani Carpenter Special Steels Ltd.; Head R&D (Retd.), JSW Steel Ltd.; Proprietor, Expert Metal Consulting, Coimbatore Title: <i>Exploiting Critical Mineral Resources for Sustainable Technologies</i>
02:50 - 03:15 PM	Invited Lecture: Dr. Dhruva Kumar Singh, Visiting Professor, IIT Dhanbad Title: <i>From Monazite to Magnets: India's Quest for Rare Earth Independence</i>
03:15 - 03:40 PM	Invited Lecture: Dr. Jayasree Biswas, Assistant Professor, IIT Bombay Title: <i>Critical Metals Extraction from Urban Ores Through Various Metallurgical Routes</i>
03:40 - 04:05 PM	Invited Lecture: Dr. Pankaj Kumar Jain, Assistant Professor, IIT (ISM) Dhanbad Title: <i>Mineral Processing: Unlocking Critical Minerals from Ore to Waste</i>
04:05 - 04:30 PM	Invited Lecture: Dr. Amit Barnwal, Assistant Professor, IIT Hyderabad Title: <i>Recovery of High-Purity Nickel from Spent NMC Lithium-Ion Battery Leach Solutions via Solvent Extraction with Versatic Acid 10 and Mixer-Settler Operations</i>
04:30 - 04:45 PM	Tea Break
04:45 - 05:45 PM	Panel Discussion: Bridging the Supply Gap in India's Critical Minerals Anchor: Dr. D.K. Das Experts: Dr. Samir V. Kamat, Dr. N. Ranjana, Mr. B.K. Soni, Dr. R. Balamurali Krishnan & Dr. G. Balachandran

26 September 2026 Technical Session 3 (Session Chair: Dr. G. Balachandran, Chairman, AMMRT Vertical of DIA-CoE IIT Kharagpur)	
09:30 - 09:55 AM	Invited Lecture: Dr. N. Venkata Rama Rao, Scientist- F, DMRL Title: <i>The Neodymium Loop: Advances and Challenges in Short-Loop Magnet Recycling</i>
09:55 - 10:20 AM	Invited Lecture: Dr. Chenna Rao, Assistant Professor, IIT Kharagpur Title: <i>Sustainable Recovery of Rare Earth Elements from NdFeB Magnets</i>
10:20 - 10:45 AM	Invited Lecture: Dr. Sudipta Patra, Assistant Professor, IIT BHU Varanasi Title: <i>A novel strategy for valorization of chromite tailings by reduction roasting with H₂ and NH₃ and magnetic separation</i>
10:45 - 11:00 AM	Tea Break
11:00 - 11:25 AM	Invited Lecture: Dr. Aarti Kumari, Assistant Professor, IIT (ISM) Dhanbad Title: <i>Advanced Separation Technologies for Sustainable Recovery of Critical Metals</i>
11:25 - 11:50 AM	Invited Lecture: Dr. Soobhankar Pati, Associate Professor, IIT Bhubaneswar Title: <i>Electrometallurgy for Sustainable Metal Extraction: Critical Materials and Beyond</i>
11:50 AM - 12:15 PM	Invited Lecture: Dr. Neha Shukla, Assistant Professor, IIT Mandi Title: <i>Sustainable Solutions for Next-Generation Electronics: The Role of E-Waste Recycling</i>
12:15 - 12:40 PM	Invited Lecture: Dr. Krishna Kumar, Scientist-E, CSIR-National Metallurgical Laboratory, Jamshedpur Title: <i>Indigenous Extraction and Recycling of Magnesium at CSIR NML</i>
12:40 - 01:00 PM	Closure & Vote of Thanks
01:00 PM Onwards	Lunch

**Mr. B. K. Soni**

Chairman & MD

Eco Recycling Limited (ECORECO), Mumbai
Email: bksoni@ecoreco.com

Mr. Soni is a Director on the MRAI, the largest Association of Recyclers in India with 1800 members. He's a member of the TEC of SERI, R2 Certification body, USA. As Chairman & Managing Director of Eco Recycling Limited (Ecoreco), he's a pioneer in e-waste management, establishing India's first authorized e-waste recycling facility in 2005. Under his leadership, Ecoreco has become key in sustainable resource management, focusing on e-waste recycling, EPR, lithium-ion battery recycling, critical mineral recovery, urban mining, reverse logistics, and data destruction. He launched BookMyJunk, India's first mobile app for responsible e-waste disposal, and Recycling on Wheels – SmartER, a mobile recycling solution supporting Smart City projects. Committed to social and environmental causes, he leads Ecoreco Foundation's initiatives in education, environment, and employment, including the Eco-Bin program to promote responsible disposal and green jobs nationwide. His efforts in India's circular economy and sustainable development are recognised internationally, and Ecoreco's work was featured in the Prime Minister's Mann Ki Baat.

Urban Mining: India's Fastest Route to Critical Mineral Security

The global transition towards clean energy, electric mobility, digital technologies, and advanced manufacturing has significantly increased the demand for critical minerals. While conventional mining remains an important source of these resources, growing supply-chain vulnerabilities, geopolitical uncertainties, and sustainability concerns necessitate the exploration of complementary pathways for resource security.

Urban mining, through the scientific recovery of valuable materials from end-of-life electrical and electronic equipment, offers a strategic opportunity to address this challenge. E-waste contains substantial quantities of precious metals, rare earth elements, and other critical minerals that can be recovered and reintroduced into the manufacturing ecosystem. As one of the world's fastest-growing generators of e-waste, India possesses a unique opportunity to transform an environmental challenge into a national resource advantage.

This study will examine the role of urban mining in strengthening India's critical mineral security, promoting circular economy principles, reducing dependence on imported raw materials, and supporting the objectives of Atmanirbhar Bharat. Drawing upon practical industry experience and emerging opportunities in critical mineral recovery, the presentation will highlight how recycling and resource recovery can complement conventional mining and contribute to building a resilient, sustainable, and self-reliant mineral ecosystem for the future.



Dr. G. Balachandran

Scientist (Retd.), DMRL, Hyderabad
Former Chief Technology Officer,
Kalyani Carpenter Special Steels Ltd.
Head R&D (Retd.), JSW Steel Ltd.
Proprietor, Expert Metal Consulting,
Coimbatore
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Dr. G. Balachandran is a distinguished metallurgist and materials technology expert with extensive experience in research and development in iron & steel, rare earth alloys. He served as a Scientist at the Defence Metallurgical Research Laboratory (DMRL), Hyderabad, where he gained insight into advanced melting processes such as VIM, VAR and ESR. In addition, he was involved in rare earth metal and Li metal extraction, where he acquired special skills in designing molten salt electrolysis and metallothermic reduction processes. His team delivered rare earth based special hydrogen storage alloy for hydrogen storage containers for defence uses and the development of Nickel-metal hydride batteries.

His industrial contributions in automotive and steel mills, cover a broad spectrum of steel development, that include nickel free high nitrogen austenitic stainless steels, high-strength steels, ultra-high-strength steels, alloy design, heat treatment, thermomechanical processing, steel melting, casting and solidification, hot rolling, forging, welding, and materials characterization. His published research also includes finite element modelling and numerical simulation of metallurgical and manufacturing processes, including solidification behaviour, ingot casting, hot rolling, forging and process optimization. He has made notable contributions to the development and processing of advanced high-strength steels covering DP steels, TRIP Steels, Quench -Partitioning steels, Medium Manganese bainitic steels, Ultra-fast heated steels. In recognition of his contribution to research and development in the iron and steel sector, He was a recipient of the National Metallurgist Award 2021 – Award for R&D in Iron & Steel Sector, conferred by the Ministry of Steel, Government of India. Following his professional career in public and private sectors, he is currently offering his technical expertise as a service through his consultancy firm Expert Metal Consulting, Coimbatore. His clients include steel mills, casting foundries, rare earth extraction plant, textile carding industry, wire drawing plants, TMT bar users, heat treaters, pump manufacturers etc.

Exploiting Critical Mineral Resources for Sustainable Technologies

Advanced technologies for promoting sustainability goals of environmental protection, economic benefit and social wellbeing, calls for the development of new products and processes that involves increased use of critical minerals. The critical minerals are crucial for a technologically advanced society that is economically advancing and feel secured against all threats. The lack of availability of these critical minerals, or extracting processes of these materials, disrupts the supply chain for the development of crucial technologies. This talk would, initially, bench mark the status of the resources of the critical minerals, supply chain and the market in the World against Indian. To focus the technological intensive nature of critical minerals, the presentation would bring forth the extraction processes developed at DMRL for the extraction of Lithium metal and Al-Li master alloys. In addition, the intricacies of rare earth extraction technologies by molten salt electrolysis and metallothermic reduction would be brought forth with a special focus on developing rare extraction in a sustainable manner using secondary resources. The processes and products developed at DMRL by the author in terms of rare earth alloy for magnets, hydrogen storage alloys and Ni-Metal hydride batteries would be brought forth.



Dr. Abhishek Mukherjee

Head, Pyrometallurgy and Metallurgical
Thermodynamics Section, Materials
Processing Division
Associate Professor, BARC, Mumbai
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Dr. Abhishek Mukherjee is the Head of the Pyrometallurgy and Metallurgical Thermodynamics Section in the Materials Processing Division at the Bhabha Atomic Research Centre (BARC), Mumbai, and an Associate Professor at the Homi Bhabha National Institute (HBNI). He received his Ph.D. in Metallurgical Engineering from IIT Bombay and carried out post-doctoral research at KU Leuven, Belgium.

His research focuses on extractive metallurgy, pyrometallurgy, electrometallurgy, and metallurgical thermodynamics, with emphasis on the development of high-temperature processes for strategic and reactive metals critical to the Department of Atomic Energy programmes. His recent contributions include indigenous process development for titanium and its derivatives, samarium-cobalt magnet powders, Pb–Li alloys for fusion applications, high-purity calcium metal, and rare-earth borides. His expertise also extends to molten salt electrolysis and high-temperature electrochemistry in molten halide systems for the extraction and refining of rare-earth elements, refractory metals, and nuclear materials.

Dr. Mukherjee has published over 26 peer-reviewed papers and holds one European patent. He is the recipient of the DAE Young Engineer Award (2011), the Ministry of Steel Young Metallurgist Award (2013), and the DAE Group Achievement Award (2017).

Advanced Extraction Technologies for Critical Metals: Challenges and Opportunities

India's pursuit in extraction of critical metals depends on mastering the complex extraction of refractory metals such as titanium, zirconium, hafnium, niobium, vanadium, tantalum, thorium, uranium, beryllium, and the rare earth elements. Producing these metals in high purity with minimal oxygen is essential for building a robust and self-reliant technological base.

To achieve this, a combination of advanced metallurgical routes is employed. For Group V metals, aluminothermic reduction of pentoxides is used, where careful control of composition and heat, guided by thermal analysis, is crucial. For Group IV metals, carbothermic chlorination followed by magnesium reduction (the Kroll process) helps overcome thermodynamic limitations, though maintaining high vacuum conditions remains a key engineering challenge.

For highly stable oxides like rare earths, fluoride-based routes are preferred. Converting oxides into fluorides enables efficient reduction using calcium, as demonstrated in rare earth processing methods.

Additionally, newer approaches like the FFC-Cambridge process offer a more direct path by removing oxygen from solid oxides electrochemically in molten salts. Together, these metallothermic, halide, and electrochemical routes form the backbone of India's strategy for indigenous, sustainable extraction and recycling of critical metals.



Dr. S. S. Kalyan Kamal

Scientist-G
DMRL, Hyderabad
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Dr. S. S. Kalyan Kamal is presently working in DMRL/ DRDO as Scientist G. He has more than 20 years of experience in Chemical characterization of materials. His areas of interest include synthesis and characterization of nanomaterials and recycling of critical materials. He has more than 40 publications

Recycling of Critical Metals as a strategic way forward for sustainable Growth: A case study of Tungsten

Traditional mining and metal extraction are critical for national security and economic growth, but supply disruptions adversely affect development. Because extracting critical materials carries a large carbon footprint and India lacks necessary indigenous processing technologies, recycling has become a strategic imperative. Metals can be recycled indefinitely within a circular economy, cutting production costs by 30–40% and lowering energy consumption significantly. Globally, recycled materials account for 25–30% of total metal production. This work presents a case study on tungsten (W) recycling from various types of scrap.

Tungsten recycling methods from cemented carbide scrap are broadly classified into direct and indirect routes. Direct routes, such as zinc treatment, consume less energy and require no chemicals, but cannot process powder scrap and often face purity issues. Conversely, indirect routes like wet chemical treatment accommodate all forms of carbide scrap and yield high-purity products, though they are highly energy-intensive and carry a heavier environmental burden.

For W-heavy alloy scrap, recycling methodologies include hydrometallurgy, oxidation-reduction, and electrolytic processes. The chemical-free oxidation-reduction route eliminates material waste through air oxidation at 900°C followed by hydrogen reduction. However, it lacks precise microstructural control and suffers from non-uniform reduction temperatures. Hydrometallurgical processes dissolve scrap using nitrates or alkaline mixtures to precipitate tungsten compounds, providing high purity on a large scale but generating high chemical volumes and exothermic control issues.

As technology drives up critical metals demand, establishing sustainable domestic extraction and recycling frameworks through R&D is imperative. Transitioning from linear extraction toward urban mining of secondary resources is vital. India must build formal scrap collection networks and implement traceable, recyclable product designs. Transitioning to cleaner extraction technologies coupled with a circular economy remains the ultimate path to sustainable development.



Dr. Raj Kumar Dishwar

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Dr. Raj Kumar Dishwar holds a B.Tech in Metallurgical Engineering from CSJMU Kanpur, an M.Tech from IIT (BHU) Varanasi, and a Ph.D. in Extractive Metallurgy from IIT (BHU), completed under Prof. O. P. Sinha. He joined IIT (ISM) Dhanbad on 15 June 2021.

His research focuses on industrial waste utilization, recovery of value-added and critical metals from ores and secondary resources, pyrometallurgy, hydrometallurgy, plasma smelting, green steelmaking technologies, and battery material recycling. He has contributed to multiple peer-reviewed journals in areas of extractive metallurgy and sustainable metal production.

Recovery of High-grade Cobalt Oxide from Zinc Plant Residue (ZPR) Generated at Zinc Processing Plants

In the present study, a method for cobalt recovery from Zinc Plant Residue (ZPR) has been developed. First, the residue was leached in a dilute sulfuric acid solution. >90% cobalt and 95% zinc were leached in two hours at room temperature. Then, leach liquor was purified before cobalt precipitation. First, copper and cadmium were removed using zinc dust. >99% copper and 80% cadmium were removed in 30 min at room temperature with slow agitation. Then, dissolved iron was removed using sodium persulfate as an oxidizing agent, and lime was used to maintain pH. Iron was precipitated (~99%) in 1 h at 60 °C temperature by maintaining pH at 3.5 and Eh at 700 mV. After iron removal, cobalt was precipitated by using sodium persulfate as an oxidizing agent, and sodium hydroxide was used to maintain pH. The cobalt precipitate was calcined and then the final product was obtained with 58% Co. The filtrate, obtained after cobalt precipitation, had a zinc concentration of approximately 69 g/L. About 82% cobalt and 90% zinc were recovered in the entire process.

Highlights:

- This work efficiently removes cobalt from the zinc plant residue using sodium persulfate as an oxidizing agent.
- The utilization of sodium persulfate as an oxidizing agent to recover high-grade cobalt as Co₃O₄ is a new concept.
- This work is original and performed at the lab scale with a proper elemental balance and a flowsheet which can be used for the scale-up operation.

This work is very ethical and important for industries to recover valuable metals from waste.



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Dr. Shivendra Sinha, a specialises in minerals, metals, and materials engineering. With 12 years in the Metal Extraction & Recycling Division, he has contributed to extractive metallurgy and critical metals processing. He earned his B.Tech from NIT Raipur, M.Tech, and Ph.d. from the Academy of Scientific and Innovative Research, focusing on metallurgical processes and sustainable resource recovery.

His expertise includes non-ferrous metal extraction, hydrometallurgy, pyrometallurgy, solvent extraction, scale-up, and pilot studies, mainly working on recovering and recycling valuable metals for India's strategic materials sector. Over the years, he has received several awards: NRDC award for technology development, Mishra Award from IIME, Nijhawan Award from CSIR-NML, Best Paper Award at MetWaste 2020, and Best Paper Presentation at National Metallurgical Day. He also earned Marie Curie Fellowship at KU Leuven and Queensland Fellowship at The University of Queensland for doctoral research. Through his research, publications, and technology development, Dr. Sinha has advanced sustainable metal extraction and recycling, supporting resource utilization, critical metal recovery, and circular economy efforts.

Interventions by CSIR-NML towards Critical Metal Recycling Technologies: Bench Scale to Pilot Scale

Co-author(s): Sanjay Kumar and Sandip Ghosh Chowdhury

Critical metals such as lithium, cobalt, nickel, manganese, rare earth elements, and precious metals are indispensable for modern energy storage systems, electric vehicles, electronics, aerospace, and strategic industries. Growing demand and limited primary resources have intensified the need for sustainable recycling and resource recovery technologies. In this context, CSIR-National Metallurgical Laboratory (CSIR-NML), Jamshedpur, has undertaken significant interventions toward the development of indigenous critical metal recycling technologies, progressing from bench-scale investigations to pilot-scale demonstrations. CSIR-NML has developed integrated pyro-, hydro-, and electrometallurgical processes for the recovery of critical metals from secondary resources such as spent lithium-ion batteries, electronic waste, waste permanent magnets, fluorescent lamps, red mud, and industrial residues. Bench-scale studies focused on process optimization involving selective leaching, solvent extraction, precipitation, electrowinning, and purification routes for achieving high recovery and product purity. These studies have further been translated into pilot-scale facilities to validate process scalability, operational stability, and technoeconomic feasibility. NML has developed pilot-scale technologies for recovery of tungsten, Lithium, Potassium, Tin, Antimony, Cobalt, Nickel, Copper and other allied elements in collaboration with industry partners. The institute has also contributed toward urban mining initiatives through recycling of e-waste and strategic metal-bearing industrial wastes under a circular economy framework. These interventions demonstrate CSIR-NML's crucial role in strengthening India's self-reliance in critical minerals, promoting sustainable metallurgy, minimizing environmental impact, and enabling industrial deployment of advanced recycling technologies from laboratory to pilot scale.



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Beyond Frameworks: Engineering Metal–Organic Materials for Emerging Energy Technologies

Co-author(s): Kumar Biradha

Rising global energy demand, driven by population growth, rapid industrialization, and modern lifestyles, highlights the urgent need for sustainable and carbon-free energy technologies. Fuel cells, enabled by advances in proton and electronic conductivity, offer efficient pathways for clean power generation, while supercapacitors provide rapid energy storage essential for next-generation electronic devices. 1. In parallel, the era of artificial intelligence and machine learning increasingly relies on advanced semiconductor materials, which play a crucial role in energy conversion, storage, and sensing technologies. 2. Metal-organic frameworks (MOFs) have emerged as a versatile class of materials owing to their high surface area, tunable porosity, and structural diversity. These unique attributes make them highly attractive for applications ranging from energy conversion and storage to selective sensing. Furthermore, their integration into nanocomposites, mixed-matrix membranes (MMMs), and thin films is opening new opportunities for industrially relevant technologies. We demonstrate this potential through several notable advances.

(a) A Ni-MOF/graphene nanocomposite, employed as the positive electrode in an asymmetric supercapacitor, delivered outstanding power density and efficient charge-storage performance.

(b) A cost-effective coordination polymer (CP)-based mixed-matrix membrane exhibited superprotonic conductivity of $4.69 \times 10^{-2} \text{ S cm}^{-1}$ at 80°C and 98% relative humidity, along with excellent long-term stability for fuel-cell applications.

(c) Our first Zn-based composite membrane for H_2S detection achieved an exceptionally low detection limit of $5.3 \mu\text{m}$.

(d) A Ni-based metal-organic gel developed by us undergoes insulator-to-semiconductor transformation via a $[2+2]$ photochemical reaction and Li^+ doping, while simultaneously exhibiting record-high Li-ion conductivity. This was reported by us for the first time.

All the above materials were successfully scaled up and processed into nanocomposites, thin films, and flexible membranes, enabling practical applications in supercapacitors, proton-conducting devices, semiconductors, and gas sensors.



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Dr. Dhruva Kumar Singh has held prominent positions including Head of Hydrometallurgy & Rare Earth Development at BARC, Mumbai, and Professor at Homi Bhabha National Institute. An expert in rare earth processing and critical minerals, he has over 30 years of experience in developing extraction and recovery technologies from primary and secondary sources. He earned his Ph.D. from the University of Mumbai and completed postdoc research at Florida State University. Dr. Singh has mentored numerous students, authored over 300 publications, and contributed to national scientific committees, including those by NITI Aayog. His achievements have earned prestigious awards like the Metallurgist of the Year, IIM Hindustan Zinc Gold Medal, VASVIK, INS Medal, DAE Awards, and various Lifetime Achievement honours.

From Monazite to Magnets: India's Quest for Rare Earth Independence

Rare earth elements (REEs) are indispensable to modern technologies, underpinning electric mobility, renewable energy systems, advanced electronics, defense platforms, aerospace applications, and emerging quantum technologies. The dominance of a few countries in rare earth mining, separation, metal production, and magnet manufacturing has exposed significant vulnerabilities in global supply chains, making the development of resilient domestic capabilities a strategic necessity.

India possesses substantial monazite resources hosted in its beach sand deposits and has established indigenous expertise in the extraction and separation of light rare earths. However, major gaps remain in downstream value addition, including the production of high-purity rare earth oxides, heavy rare earths, metals, alloys, Nd-Fe-B and Sm-Co permanent magnets, and advanced functional materials. Addressing these gaps is critical to achieving technological sovereignty and realizing the vision of Viksit Bharat 2047.

This lecture examines the scientific, technological, and policy dimensions of building an integrated Indian rare earth value chain—from resource characterization, beneficiation, cracking and leaching of monazite, solvent extraction-based separation, purification, and metal production to alloy preparation, magnet fabrication, recycling, and end-use deployment. Particular emphasis will be placed on process innovations for sustainable rare earth processing, including intensified solvent extraction, membrane-assisted separations, ionic liquids and deep eutectic solvents, bio-hydrometallurgical approaches, digital process optimization, and recovery from secondary resources such as end-of-life magnets and industrial wastes. Drawing on global experiences and India's technological strengths, the presentation outlines a strategic "mine-to-magnet" roadmap involving coordinated investments in R&D, pilot-scale demonstration, manufacturing capability, recycling infrastructure, and public-private partnerships. Rare earth independence is not merely a resource challenge but a technology challenge requiring mastery across the entire value chain. Converting India's monazite advantage into downstream manufacturing leadership will be essential for ensuring energy security, strategic autonomy, and long-term industrial competitiveness.



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Prof. Jayasree obtained her Ph.D. in Process Metallurgy from McMaster University, Canada, in 2021, following her M.Tech. in Process Engineering from IIT Bombay and B.E. in Metallurgical and Materials Engineering from Jadavpur University. Prior to joining IIT Bombay in 2024, she worked as a Postdoctoral Researcher at Aalto University, Finland, and as a Researcher at Tata Research Development and Design Centre (TRDDC), Pune.

Her research focuses on sustainable metal extraction and refining, including metal recycling from secondary resources such as e-waste, spent batteries, and waste solar cells, green steelmaking, high-temperature process metallurgy, metal refining, process thermodynamics and kinetics, and process modelling. Through her research, she aims to develop sustainable technologies for resource recovery and environmentally responsible metallurgical processing.

Prof. Biswas has authored numerous publications in leading international journals and has contributed significantly to advancing sustainable metallurgical processes, critical metal recovery, and circular economy technologies. Her current research activities at IIT Bombay include battery recycling, green steelmaking, and sustainable metal extraction from primary and secondary resources.

Critical Metals Extraction from Urban Ores Through Various Metallurgical Routes

Recovery of metals such as Li, Co, Ni, Cu, and rare earth elements from secondary sources has become essential due to their strategic importance and the criticality of supply. Spent Li-ion batteries contain valuable metals – Li, Co and graphite in significant quantities, and spent REE magnets contain 15-20% REEs. Selective roasting followed by water leaching is promising for the extraction of selected metals from these secondary ores, by controlling the roasting environment and temperature at the first stage of the recycling process. Experimental studies with LCO black mass have demonstrated that selective extraction of Li >95% is possible at the first stage, while leaving Co oxide in the residue. This is similarly observed for LFP cathode scrap, where selective recovery of more than 90% Li was possible in the first stage of processing. Furthermore, selective extraction of REE from spent magnets is found to be challenging due to the slow kinetics of the roasting reaction of REEs.



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Prof. Pankaj Kumar expertise in mineral beneficiation, physical separation processes, critical mineral processing, and mineral processing equipment design and development. He obtained his B.Tech. and M.Tech. in Mineral Engineering and Mineral Resource Management from ISM Dhanbad and his Ph.D. in Mineral Engineering from IIT (ISM) Dhanbad, with research focused on the recovery of iron values from low-grade tailings.

His research interests include gravity concentration, froth flotation, critical minerals, rare earth mineral processing, e-waste processing, dry processing, and the development of mineral processing equipment. His research activities cover the beneficiation and recovery of valuable resources from low-grade graphite, gold ore, iron ore, Cr-Ni ore, coal rejects, e-waste, and rare earth-bearing materials. Prof. Jain has also worked on process flowsheet design, equipment selection, fine and low-grade mineral processing, and recovery of critical and strategic metals. His research includes projects related to rare earth element beneficiation, gold recovery, enhanced gravity separation, high-tension separation, and recovery of metals from e-waste. He has published research in peer-reviewed journals and has contributed chapters on gravity, electrostatic, magnetic, and flotation separation in publications by Elsevier. His expertise in critical mineral processing, resource recovery, and sustainable mineral beneficiation makes him a valuable contributor to discussions on the processing and recovery of critical metals and minerals.

Mineral Processing: Unlocking Critical Minerals from Ore to Waste

Mineral processing is essential for efficient extraction and recycling of critical minerals, involving the physical separation of valuable minerals from gangue based on differences in density, magnetic susceptibility, electrical conductivity, surface hydrophobicity, or optical properties. This upgrading of ore grade reduces the volume and improves the efficiency of downstream chemical or pyrometallurgical processes. For primary sources in India, such as monazite (REE), ilmenite/rutile (Ti), zircon (Zr), spodumene (Li), flake graphite, wolframite (W), coltan (Nb-Ta), chalcopyrite (Cu), and cassiterite (Sn), conventional circuits employing gravity concentration, magnetic and electrostatic separation, froth flotation, and sensor-based sorting achieve high-purity concentrates after liberation at appropriate sizes.

Secondary sources—including laterite overburden, coal fly ash, anode slimes, smelter residues, and industrial wastes—often lack inherent physical distinctions due to ionic substitution or fine locking. These may require use of phase transformation techniques to induce artificial distinction in the physical properties else they have to be directly subjected to extraction routes. Certain minerals with atomic-level locking (e.g., Ga in bauxite liquors, Ge/In in zinc residues), direct hydrometallurgical or electrolytic routes are required.

As ore grades decline, ultrafine liberation ($<20\ \mu\text{m}$) necessitates advanced technologies including centrifugal gravity concentrators, high-gradient magnetic separators, tribo-electrostatic systems, and specialized flotation cells (Concorde, Jameson). Upfront beneficiation delivers major economic and environmental gains by reducing feed mass 75–95%, cutting reagent and energy use 60–80%, lowering transport costs, and minimizing hazardous tailings. In the Indian context, integrated physical processing thus underpins sustainable critical-mineral supply chains for energy transition and strategic industries.



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Dr. Amit Barnwal's research areas include non-ferrous extractive metallurgy, mineral processing, sustainable recycling, and recovering critical and rare-earth metals from primary and secondary resources. Before joining IIT Hyderabad in March 2026, he was a Postdoctoral Researcher at Chalmers University of Technology, Sweden, focusing on extracting high-purity manganese, cobalt, and nickel sulphate salts from spent lithium-ion batteries via solvent extraction. He also worked as a Research Scientist and Project Scientist at C-MET, developing e-waste processing and sustainable recycling methods for lithium-ion batteries. He earned his Ph.D. in Metallurgical and Materials Engineering from IIT Roorkee, focusing on recycling printed circuit boards for valuable metals. His work developed hydrometallurgical and pyrometallurgical processes for recycling lithium-ion batteries and e-waste, scaling up to pilot plants and industry transfer in India. He holds two U.S. patents on lithium-ion battery recycling and has published in top journals. His research includes non-ferrous metallurgy, battery recycling, e-waste management, hydrometallurgy, solvent extraction, critical metals recovery, mineral beneficiation, and sustainable.

Recovery of High-Purity Nickel from Spent NMC Lithium-Ion Battery Leach Solutions via Solvent Extraction with Versatic Acid 10 and Mixer–Settler Operations

The rapid growth of electric mobility and advanced electronic technologies has significantly increased the global demand for critical strategic metals, creating an urgent need for sustainable approaches to recover valuable resources from end-of-life lithium-ion batteries (LIBs). Nickel (Ni), a key component in high-energy-density cathode materials, plays a crucial role in next-generation battery technologies due to its excellent energy storage capability, corrosion resistance, and mechanical strength. However, the limited availability of primary nickel resources and increasing supply chain challenges have highlighted the importance of recovering nickel from secondary resources, particularly spent lithium-ion batteries.

This presentation will discuss the development of an integrated hydrometallurgical process for the selective recovery and purification of nickel from spent NMC (LiNiMnCoO_2) lithium-ion batteries. The proposed approach combines selective solvent extraction using Versatic Acid 10, continuous mixer–settler operation, and evaporative crystallization for the production of high-purity battery-grade nickel sulphate hexahydrate ($\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$). The optimized solvent extraction strategy enabled highly selective nickel separation with recovery exceeding 99% through a two-stage counter-current mixer–settler configuration, followed by efficient stripping and crystallization to obtain nickel sulphate with purity greater than 99%.

The recovered nickel sulphate product was comprehensively characterized using ICP-OES, SEM, and XRD analyses, confirming its chemical purity, crystalline structure, and suitability as a precursor material for nickel-rich lithium-ion battery cathode synthesis. The presentation will highlight the critical role of solvent extraction and crystallization technologies in achieving selective metal recovery and transforming waste battery materials into high-value battery-grade products.



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Dr. Rama Rao currently working as Scientist F at DMRL, Hyderabad. His area of research includes Rare-earth (RE) permanent magnets (PM), RE-free PMs, nanocomposite magnets, Magneto-caloric materials, 3D printing of magnetic materials and recycling of RE magnets. He has published more than 50 research papers in reputed international journals and co-authored a book chapter on Recent Developments in Nanostructured Permanent Magnet Materials and Their Processing Methods and filed 5 patents. He is fellow of telangana academy of sciences and treasurer, Magnetics Society of India (MSI).

The Neodymium Loop: Advances and Challenges in Short-Loop Magnet Recycling

Rare earth permanent magnets (REPM) are widely used in strategic and civilian sectors including clean energy. The rapid expansion of clean energy technologies has driven unprecedented global demand particularly for Nd-Fe-B permanent magnets. Rare earth elements (REE), the key elements of high-performance magnets, are considered critical materials, as their resources, processing and supply are geographically confined to few countries. The growing demand coupled with critical nature of the materials has intensified concerns over the sustainability and security of REE supply chains. Considering the environmental concerns surrounding primary rare-earth mining and limited availability, it is imperative to develop secondary sources to meet the growing demand. Therefore, recovery and reutilization of these magnets from the end of life (EOL) products through viable recycling techniques are of great significance. Short-loop magnet (direct magnet to magnet) recycling has emerged as a promising strategy to recover and reprocess scrap/EOL Nd-Fe-B magnets while preserving their intrinsic microstructure, composition and phase. This process reduces energy consumption, material losses, and environmental impacts compared to conventional hydrometallurgical and pyrometallurgical recycling routes. Recent advances in short-loop recycling include improved collection and sorting techniques, hydrogen processing of magnetic scrap, direct re-sintering, and grain boundary diffusion processes. These methods enable the production of recycled magnets with restored magnetic properties approaching those of original materials. Despite these advances, several challenges continue to limit large scale adoption. The EOL magnet stream comprise of mixed magnet grades with diverse compositions remain a primary hurdle as it can adversely affect magnetic performance of reprocessed magnets. In addition, surface coatings, contamination, oxidation severely degrade magnetic performance if not properly managed during pre-processing. Having developed the lab scale Nd-Fe-B magnet technology, DMRL has initiated research activities on recycling of Nd-Fe-B magnets and short loop magnet recycling of lab scrap and EOL magnets has been successfully developed with realization of more than 80% of the original magnet properties in the reprocessed magnets. The talk will bring out DMRL efforts in Nd-Fe-B magnet recycling in general, and discuss the current state-of-the-art highlighting critical bottlenecks and outlines pathways towards developing sustainable and circular Nd-Fe-B magnet recycling processes capable of meeting the growing demand.



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Dr. Chenna Rao Borra's research focuses on Extractive Metallurgy, Hydrometallurgy, Pyrometallurgy, Metal Recycling, Waste Valorization, and Sustainable Metallurgy, with particular emphasis on the recovery of valuable metals and critical resources from primary and secondary sources.

Prior to joining IIT Kharagpur in 2019, Dr. Borra worked as a Senior Scientist at Aditya Birla Science and Technology Company and held research positions at Delft University of Technology, The Netherlands, and KU Leuven, Belgium. He also worked in R&D at Tata Steel and at the Non-Ferrous Materials Technology Development Centre (NFTDC), Hyderabad.

Dr. Borra leads the Sustainable Material Extraction (SME) Laboratory at IIT Kharagpur, where his research addresses sustainable extraction technologies, recycling of metals, circular economy approaches, and resource-efficient processing of industrial wastes. He has authored numerous publications in reputed international journals and has made significant contributions to the fields of extractive metallurgy and sustainable materials processing.

Sustainable Recovery of Rare Earth Elements from NdFeB Magnets

Recovering rare earth elements (REEs) from waste resources extends mine life, reduces supply criticality, and supports sustainability. This presentation discusses resource- and energy-efficient processes for recovering REEs from end-of-life NdFeB magnets while overcoming the limitations of conventional direct leaching, which requires large amounts of acid and generates significant waste. A smelting-based approach selectively oxidizes REEs using Fe_2O_3 and B_2O_3 , achieving over 99% recovery, followed by acid leaching to recover rare earths as double sulfates and boron as boric acid. A selective leaching process was also developed that dissolves only rare earths, significantly reducing acid consumption, reagent use, and waste generation. Furthermore, an integrated hydrometallurgical process for the selective recovery and purification of rare earth elements enables the production of high-purity rare earth compounds (>99%) with high recovery efficiencies while minimizing chemical consumption and liquid effluent generation. The process has been successfully demonstrated at pilot scale, highlighting its scalability and industrial applicability. In addition, a novel synergistic recycling strategy integrates NdFeB magnet recycling with lithium-ion battery processing by reusing waste ferrous sulfate generated during magnet leaching as a reductive agent for battery cathodes, enabling recovery efficiencies above 95% for REEs, Li, Co, Ni, and Mn. Overall, the proposed approaches provide scalable, resource-efficient, and circular solutions for sustainable recovery and purification of rare earth elements from secondary resources.



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Dr. Sudipta Patra obtained his B.E. in Metallurgical and Materials Engineering from BESU (now IEST Shibpur) in 2009, followed by an M.S. (2012) and Ph.D. (2019) from IIT Kharagpur. Before joining IIT (BHU) in 2020, he worked as a Senior Manager (R&D) at Jindal Stainless Limited for eight years and later served as a Postdoctoral Fellow at the University of British Columbia, Canada. His research focuses on stainless steels, alloy steel development, thermomechanical processing, microstructure-property relationships, crystallographic texture, industrial failure analysis, steelmaking, and waste utilization. He has led and collaborated on several government- and industry-sponsored research projects related to advanced steels for structural, naval, and energy applications, and teaches courses including Iron Making Technology, Stainless Steel Technology, Heat Treatment.

A Novel Strategy for Valorization of Chromite Tailings by Reduction Roasting with H_2 and NH_3 and Magnetic Separation

Co-author(s): Sayantan Mukherjee, Prem Singh, Rohit Jha, Ammasi A. and Kamallesh K. Singh

Chromite ore processing tailings (COPT) contain significant quantities of iron and chromium, making them a potential secondary resource for sustainable metal recovery. In the present study, selective reduction of iron oxide in COPT using H_2 and NH_3 was investigated at 823 K and 1173 K for 2 hours, followed by wet low-intensity magnetic separation. X-ray diffraction analysis revealed that NH_3 exhibited superior reduction performance at 823 K, converting approximately 96% of hematite (Fe_2O_3) to magnetite (Fe_3O_4), whereas H_2 achieved only about 12% conversion under identical conditions. At 1173 K, both reducing atmospheres produced similar phase evolution, with complete hematite reduction but extensive formation of fayalite (Fe_2SiO_4) through reaction of FeO with SiO_2 , thereby limiting magnetic beneficiation. Owing to the highest magnetite content, the NH_3 -reduced sample at 823 K was subjected to magnetic separation. The magnetic concentrate contained approximately 94.8 wt.% Fe_3O_4 with 68.6 wt.% Fe, corresponding to about 77% iron recovery. The non-magnetic fraction contained 19.2 wt.% Cr (28.1 wt.% Cr_2O_3), with approximately 97% chromium recovery, while the material loss during separation was only 1.8 wt.%. The results demonstrate that low-temperature ammonia reduction followed by magnetic separation is an efficient and sustainable route for selective iron recovery and chromium enrichment from chromite ore processing tailings, enabling their valorization as valuable secondary resources. The study further explores the recovery of Ni, Co and other valuable elements.



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Dr. Aarti Kumari has over 12 years of research experience in the fields of hydrometallurgy, critical metal and rare earths extraction, non-ferrous metal processing, recycling, and sustainable resource recovery. She has made significant contributions to the development of environmentally benign processes for recovering critical metals from secondary resources and has led several nationally and internationally funded research projects.

Prior to joining IIT (ISM) Dhanbad in 2022, Dr. Kumari served as a Scientist and later Senior Scientist at CSIR–National Metallurgical Laboratory (CSIR-NML), Jamshedpur, where she contributed significantly to the development of technologies for the recovery of rare earth elements and critical metals from secondary resources. She obtained her Ph.D. from the Academy of Scientific and Innovative Research (AcSIR), with research focused on the hydrometallurgical processing of spent NdFeB magnets for rare earth recovery. Dr. Kumari has authored numerous research publications in reputed international journals and holds patents related to rare earth recovery and recycling technologies. Her contributions have been recognized through several prestigious awards, including the IEI Young Engineers Award (2023–24), the AWSAR Award from the Department of Science and Technology (DST), Government of India, and multiple best paper and presentation awards in national and international conferences.

Advanced Separation Technologies for Sustainable Recovery of Critical Metals

The increasing demand for critical metals and rare earth elements (REEs) driven by clean energy technologies, electric vehicles, and advanced electronics has intensified the need for sustainable resource recovery. While conventional mining faces challenges related to resource depletion, environmental impact, and supply chain risks, secondary resources such as spent permanent magnets, lithium-ion batteries, electronic waste, and industrial residues offer a promising alternative for securing critical raw materials. This lecture will highlight the importance of process intensification and green separation technologies for efficient critical metal recovery. Particular emphasis will be placed on microwave-assisted heating and ultrasonication, which enhance reaction kinetics, improve mass transfer, reduce processing time, and lower energy consumption during extraction. The synergistic integration of these techniques enables the development of efficient and economically viable hydrometallurgical processes. The talk will further discuss the emerging role of deep eutectic solvents (DES) as environmentally benign and highly tunable media for selective metal extraction and separation. Their unique physicochemical properties offer improved selectivity and lower environmental impact compared with conventional solvents. By integrating microwave heating, ultrasonication, and DES-based separation, next-generation extraction processes can achieve higher recovery efficiencies, superior selectivity, and improved sustainability. These emerging technologies offer significant opportunities to overcome existing challenges and enable circular, energy-efficient, and environmentally responsible pathways for critical metal recovery.



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Dr. Soobhankar Pati obtained his Ph.D. in Materials Science and Engineering from Boston University, USA, M.Tech. in Metallurgy from IIT Kharagpur, and B.Tech. in Ceramic Engineering from NIT Rourkela. Prior to joining IIT Bhubaneswar in 2012, he worked as a Research Engineer at Infrinium Metals Inc., USA.

His research focuses on electrometallurgy, electrochemical engineering, extraction and recycling of metals, lithium-ion batteries, hydrogen energy materials, fuel cells, and sustainable low-carbon metal extraction technologies. He has developed several innovative technologies and holds patents in the areas of metal extraction and electrochemical processing.

Dr. Pati has led and contributed to numerous sponsored research projects supported by DST, SERB, Tata Steel, NALCO, DRDO, and the Ministry of Mines. He is the recipient of several prestigious awards, including the TMS Young Professional Development Award, the Mann Redmayne Award (IOM3), the Electrochemical Society Student Award, and the IOCL Start-up Award. In addition to his academic contributions, he serves as the CEO of the IIT Bhubaneswar Research and Entrepreneurship Park, promoting innovation, entrepreneurship, and industry-academia collaboration.

Electrometallurgy for Sustainable Metal Extraction: Critical Materials and Beyond

Co-author(s): Satya Prakash Padhee and Brighty Dutta

The increasing demand for critical materials required for clean energy, aerospace, defence, and advanced manufacturing has renewed interest in electrometallurgy as a sustainable metal extraction technology. While electrometallurgical processes have long been employed in the production and refining of metals, recent developments in molten-salt electrochemical technologies have significantly expanded their scope toward the extraction of reactive and strategic metals. Emerging processes such as the FFC Cambridge process, Solid Oxide Membrane (SOM) process, and Ono-Suzuki (OS) process offer promising alternatives to conventional extraction routes by reducing process complexity, energy consumption, and environmental impact.

This presentation reviews recent advances in electrometallurgical extraction, with particular emphasis on titanium production from ilmenite and titanium oxides, while extending the discussion to other critical materials, including rare earth elements, vanadium, niobium, lithium, cobalt, nickel, and chromium. Drawing upon research in molten-salt electro-deoxidation, aluminum electrodeposition, vanadium-bearing titanomagnetite processing, and battery materials, the talk will discuss the scientific principles, current challenges, and industrial prospects of advanced electrochemical extraction technologies. The presentation concludes by highlighting the pivotal role of electrometallurgy in developing sustainable, low-carbon, and resilient supply chains for critical materials and positioning India as a leader in next-generation extractive metallurgy.



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Dr. Neha Shukla obtained her Ph.D. in Metallurgical and Materials Engineering from the Indian Institute of Technology Roorkee. Her research focuses on extractive metallurgy, critical minerals, rare earth elements, waste valorization, and sustainable resource recovery from primary and secondary sources.

Prior to joining IIT Mandi in 2024, Dr. Shukla carried out extensive research in the field of rare earth extraction and recycling. Her work has contributed to the development of environmentally sustainable processes for recovering rare earth elements from end-of-life products, including waste fluorescent lamp phosphors. She is the inventor of a patented process for the recovery of rare earth oxides using microwave acid baking technology.

Dr. Shukla has authored several research publications in reputed international journals and is actively engaged in research on critical metal recovery, circular economy approaches, waste management, and sustainable materials processing. Her current research aims to advance resource security through innovative technologies for the extraction, separation, and recycling of critical and strategic materials.

Sustainable Solutions for Next-Generation Electronics: The Role of E-Waste Recycling

The recycling of rare earth elements (REEs) from electronic waste (e-waste) and their integration into thin-film transistors (TFTs), photodetectors, and memristors offers a sustainable pathway for enhancing next-generation, cost-effective electronics. The current study targets two key objectives: first, developing advanced techniques for recovering high-purity rare earth oxides (REOs) from e-waste; second, leveraging these reclaimed REOs as dielectric materials or alloyed semiconductors in optoelectronic devices, with a primary focus on transistors (switching device). TFTs comprise multiple layers, each utilizing distinct electronic materials, including REOs, to enhance device performance and efficiency. This approach not only promotes resource sustainability but also improves the overall efficiency of future electronic components. The development of indigenous electronic components using critical raw materials sourced from e-waste advances the country's technological self-reliance. Key materials, such as rare earth metals, will be extracted from e-waste sources, including fluorescent lamps (FLs), and LEDs. Elements such as Y, Eu, La, Tb, and Ce will be recovered through an alkali roasting process that utilizes cost-effective fluxes to break down phosphor phases into water-insoluble rare-earth hydroxides. The method of developing a solution-processed amorphous indium-zinc-tin oxide (a-IZTO) TFT using a water-based yttrium oxide (Y_2O_3) passivation layer, significantly improves the stability of the IZTO TFT. Thus, many rare earth metals form strong bonds with oxygen and play a vital role as protective layers for semiconductors in electronic devices. Our approach to utilizing recovered REOs shows great potential for next-generation electronics. Ultimately, the study aims to scale these processes for industrial applications, thereby promoting sustainable electronics manufacturing.



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Dr. Krishna Kumar, a Scientist-E at CSIR-NML in Jamshedpur, holds an M.Tech. and specializes in Extractive Metallurgy, Chemical Metallurgy, Magnesium Metal Extraction, Vacuum Distillation, and Process Design. His research focuses on extracting and refining non-ferrous metals like magnesium and sodium, developing ultra-high-purity metals and compounds. His broader interests include process development, mineral processing, energy efficiency, life-cycle assessment, and sustainable metal production.

Dr. Kumar has extensive experience in high-temperature metallurgical processing and utilizes advanced tools such as FactSage, MATLAB, design-of-experiments methodologies, and process thermodynamics and kinetics for technology development and optimization. His work contributes to advancing indigenous capabilities in metal extraction, refining, recycling, and sustainable resource utilization.

Indigenous Extraction and Recycling of Magnesium at CSIR NML

Magnesium (Mg) metal holds a critical position due to its ultra-low density, high strength-to-weight ratio, and immense potential in aerospace, automotive, and defense sectors i.e. reductant for Titanium and Zirconium extraction plants. Driven by rapid growth in automotive light-weighting and electric- vehicle (EV) manufacturing, the global metal magnesium demand stands at approximately 1.27 million tons and is projected to expand at a Compound Annual Growth Rate (CAGR) of 5.08% to reach 1.63 million tons. Concurrently, the Indian magnesium market is undergoing significant expansion, growing at a CAGR of 5.1% to meet requirements across domestic industries. India imports roughly 120 million USD worth of primary magnesium annually and over 90 % of these imports sourced from China, making the domestic supply chain highly vulnerable to price volatility and foreign export policies. To counter this single-source import vulnerability and align with national technological sovereignty, under special project scheme (CSPS), CSIR has launched and initiative to pilot the complete extraction scheme integrated with vacuum distillation refining and recycling at 120 kg Mg metal/day scale with commercial (99.8 %) and high pure (99.95%) purity. Since 1960s, CSIR-NML focuses heavily on extraction metallurgy from domestic dolomites through silicothermic reduction technologies. NML has optimized thermal reduction processes with innovations for vacuum distillation-based refining and recycling in last 10 years. Magnesium metal extraction pilot plant is based on retort-based silico-thermic reduction of calcined dolomite under vacuum (at 600 kg feed scale) and integration of vacuum distillation technology for refining and recycling at 120 kg scale. Proposed piloting consists raw material preparation unit with 2TPD rotary kiln and dry press briquetting facilities, 6 retort extraction line, 10 kg vacuum induction melting and 120 kg continuous magnesium distillation and casting facility planned for demonstrations at upto 2 TPD feed of dolomite and 120 -140 kg Mg metal/day to stakeholders. This piloting initiative will lead to development of Mg technologies at TRL 7 for national requirements.



About DIA-CoE IIT Kharagpur

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The DRDO Industry Academia-Centre of Excellence at the Indian Institute of Technology Kharagpur (DIA-CoE IIT Kharagpur) was established by the Defence Research and Development Organisation (DRDO). The Centre serves as a platform to strengthen collaboration among academia, DRDO laboratories, industry, and start-ups, translating scientific research into innovative technologies for national security.

By bringing together faculty members, researchers, DRDO scientists, and industry experts, the CoE drives interdisciplinary research, technology development, prototype validation, and knowledge exchange in areas of strategic importance.

The core research activities at the Centre are organized under six specialized verticals:

- Advanced Extractive Metallurgy and Metal Recycling Technologies (AEMMRT)
- Advanced Surface Engineering Technologies (ASET)
- Unmanned Underwater Robotic Sensors and Actuators (UURSA)
- Cognitive Technologies and Cyber Physical Defence Systems (CTCPDS)
- Quality, Reliability and Safety Studies (QRSS)
- Cryptography and Information Security (CIS)

Through these verticals, the CoE facilitates cutting-edge work spanning critical mineral processing, surface engineering, underwater robotics, artificial intelligence, and cybersecurity. By bridging fundamental laboratory research with practical technological deployment, the Centre supports DRDO's mission to develop indigenous, high-TRL defence solutions.

Ultimately, DIA-CoE IIT Kharagpur fosters powerful, multi-sector partnerships that advance scientific discovery, catalyze technology innovation, and deliver next-generation engineering systems to meet India's vital national strategic needs.

