ASIA CENTRE - ICWA

JOINT SEMINAR

CRITICAL MINERALS AND RARE EARTHS : COMPLEXITIES, GEOPOLITICS & THE WAY AHEAD

INTRODUCTION

Asia Centre, Bangalore organised a joint seminar with the Indian Council of World Affairs (ICWA) at the IAS officers' Association Auditorium, Infantry Road, Bangalore on 8 January 2026. Topic of the seminar was "Critical Minerals and Rare Earths: Complexities, Geopolitics & The Way Forward".

Asia Centre Bangalore is a think tank focusing on Politics and Security in the Asia Region. The Centre has been registered as a Society under the Karnataka Societies Registration Act, 1960. Mrs Latha Reddy, IFS (Retd) is the Chairperson and Lt Gen C.A. Krishnan, PVSM, UYSM, AVSM is the Director.

Asia Centre Bangalore is an independent, non-partisan Institute; a think tank dealing with all aspects of defence and security. It is a multi-disciplinary organisation drawing its members from former policy makers, academics, diplomats, defence service officers, development bankers, researchers, authors, and captains of industry. ACB provides a platform for free exchange of ideas and analysis leading to policy inputs for leaders in Government, business, industry and the civil society. Asia Centre conducts seminars, lectures, studies and 'Track two' dialogues on issues of topical importance.

Asia Centre's mission is to encourage and facilitate independent debate on defence and security in India and across the wider world. The Centre receives no core government funding. The Centre upholds intellectual independence. Asia Centre sets its own agenda, chooses its own topics to research and has a responsibility to reflect its research findings truthfully. The Centre rejects funding that is incompatible with its independence and intellectual honesty. This independence is maintained as an on-going process by the senior management, and overseen by the Centre's Governing Board.

The Indian Council of World Affairs was established in 1943 by a group of Indian intellectuals as a think tank. It was registered as a non-official, non-political and non-profit organisation under the Registration of Societies Act 1860. By an Act of Parliament in 2001, the Indian Council of World Affairs has been declared an institution of national importance. The Vice President of India is the ex-officio President of ICWA. Shri Ngulkham Jathom Gangte is the OSD (Establishment), MEA & Acting DDG, ICWA. The ICWA is devoted exclusively to the study of international relations and foreign affairs. The Council publishes a journal 'India Quarterly' and sponsors the publication of books on international affairs.

CRITICAL MINERALS AND RARE EARTHS :

COMPLEXITIES, GEOPOLITICS & THE WAY AHEAD

SYNOPSIS

The world is, today, defined by modern industries, Hi-tech equipment, Digitised environment, Data Centres, Semi conductors, AI, precision weapons, space exploration, Climate action, Green energy etc. These industries are dependent upon certain essential minerals as raw material. The supply chain vulnerability of these minerals have transformed them into a powerful geopolitical tool.

India shares geological similarity with mineral rich regions of the world like Western Australia, Africa and Antarctica. While international environmental protocols place prohibition on mining activities in Antarctica, other mineral rich regions like Western Australia and South Africa have successfully exploited their rich mineral resources. But unlike it's mineral-rich cousins, India, is yet to uncover and monetise its deep seated mineral resources.

Minerals are produced from mines. A mine can only be set up after confirming its economic viability through an accurate assessment. An assessment this nature, of a resource buried deep under the earths surface is a specialised job, is time consuming & involves significant expenditure. This preliminary ‘search & confirmation’ process is referred to as mineral exploration. There is no guarantee of success at the end of this ‘search’ process. The average time taken from the preliminary discovery of a mineral deposit to setting up of a mine is 15 to 17 years.

The mineral ore extracted from a mine needs to be refined. Refining is a complex and elaborate process which involves crushing, separation, concentration, purification etc and requires appropriate technology and special equipment. There are environmental concerns too.

Coming to Critical minerals, these are minerals with high economic or national security concerns and a high risk of supply disruption. The list of minerals assessed as ‘critical’ would vary from country to country.

Rare earths, a set of 17 minerals grouped under a generic name, is a typical example of critical minerals. Rare earths, per se, are not rare. What makes them ‘Rare’ is the difficulty in finding them in adequate concentration to be economically extracted.

China accounts for roughly 70% of global rare earths production. It also tops the list of assessed rare earths reserves with about 44 million metric tons. India ranks third with 6.9 million tons Rare earths reserve.

Rare Earths is an essential performance enhancer for industries worth Trillions of dollars.

Every modern hi-tech equipment and common use device today requires rare earths, albeit in small quantities. It is irreplaceable with no substitute available, as of now. Rare Earths are very critical for Renewable Energy and also plays a major role in nuclear reactors as control rods and neutron absorbers.

Till the 1980's, the Mountain Pass mine in the United States was the predominant global Rare Earths producer, supplying about 70 % of the total global Rare earths. However, the mine ran into major environmental issues in 80's and was ordered to clean up toxic tailings which proved prohibitively costly. China, blessed with abundant reserves, had been systematically catching up and was ready to step in. It looked a smart thing for the world then, particularly the US, to outsource the dirty work and environmental concerns. The situation was tailor made for China. It stepped in and by 2010, established near monopoly, not just in rare earths mining, but across the entire supply chain from the mineral ore production, to refining, to manufacturing rare earths magnets.

There are other minerals too, that are extremely essential for green energy and modern hi-tech industry. A typical modern electric car requires 6 times more mineral inputs than a conventional car. Similarly, an offshore wind plant requires 13 times more mineral resources than a gas-fired plant of similar output. Semi-conductors is another pillar of modern hi-tech industries which requires a set of high value mineral inputs.

Rare earths, Lithium, Cobalt, Nickel, Copper, Gallium, the Platinum group of minerals, Tantalum, Tellurium, Tungsten, Niobium, Indium, Germanium etc fall into the category of critical minerals of most countries. The non-replaceable status of these minerals calls for a careful study of their supply status from an Indian perspective.

India has near 100% import dependency for Rare earths as well as almost the entire minerals which are essential for green energy and modern hi-tech industries.

India and the world have now woken up to the fact that significant parts of the critical minerals supply chains including mining and refining and even the manufacturing of mid-stream components are highly concentrated, and that too in Chinese hands. China is, today, using this control over critical minerals supply chain as an effective hedge against Trump's tariff war. It is a lesson for the world.

India, with it's healthy economic growth and a GDP set to jump into the third position, is set to witness a huge rise in it's energy demand. Transition to green energy is non-negotiable for India and it has rightly set for itself very ambitious climate goals. India's rising energy demand combined with it's ambitious climate action goals will translate into huge spike in the country's demand for green energy minerals.

Even in a modest climate action scenario, in the next 10 years, the world is looking at a 100% spike in the demand for green energy minerals. In the net zero emission by 2050 scenario, the jump will be three fold.

The new global approach calling for drastic reduction in coal dependence makes it even more imperative for India to speed up it's green energy mission. India needs to be among the leaders in green energy production and related R&D activities.

India, by virtue of its national interests, cannot afford to be part of any particular global power bloc and must continue to retain its strategic autonomy at all costs. High import dependency for ingredients of economic growth will adversely impact the country's strategic autonomy. Atmanirbharta to the maximum extend and diversification of import sources as well as export markets, for goods and services, is the way ahead for India. With that kind of a scenario looming on the horizon, critical minerals seem far more critical for India than for rest of the world. It is action time and India needs to act.

India must enable private participation in mining in a big way. Mineral exploration holds the key to unlocking India's deep seated, high value, mineral resources. A well thought out and unambiguous policy for mining and Critical minerals is extremely important. The policy must ensure consistency, transparency, level playing field, time-bound single window clearance, fast track courts and appropriate incentives in terms of tax benefits & mining concession rights. India also needs to forge partnerships and joint ventures with friendly countries for upstream critical mineral resources as well as for down stream technologies to ensure a robust critical mineral supply chain. Recycling is another important source with significant potential that India must focus on.

EDITORIAL

This document is a summary of the proceedings of the seminar. It has been compiled and edited by Mr Rishi Athreya of Asia Centre and Ms Samyuktha NG, Ms Drishti Agarwal and Ms Anya Mudalpur of MS Ramiah University, under the guidance of Lt Gen CA Krishnan (Retd), Director, Asia Centre, Bangalore.

CITATION

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OVERVIEW

Ms Latha Reddy, the Chairperson of Asia Centre delivered the opening address and welcomed the delegates and the audience. Dr Nivedita Ray, Director of Research ICWA gave a short overview of the topic, encapsulating various dimensions of the critical minerals confronting the world today. Lt Gen CA Krishnan (Retd) introduced the topic and explained what critical minerals are and their strategic significance. The criticality of their assured supply on the economy and security of nations, and for the much needed transition to green energy, was highlighted. He also explained the monopolistic nature of the existing supply chains with facts and figures. This was followed by Dr VN Vasudev, a well known geologist and

Advisor on Mineral Resources and Policy, speaking on the Dynamics of Mining, Mineral Production & What India can do. He elaborated on the time consuming preliminary processes that goes into establishing a mine. Mr Pranay Kotasthane, Dy Director, Takshashila Institution, thereafter discussed in detail the "Geopolitics of Critical Minerals". Dr Amit Tripathi, President, Geoexploration LLC, explained "Future Trends and Technology in Mining & Global initiatives in Critical Minerals and Rare Earths". Thereafter, Dr Abhinav Mathur, Advisor to the Board, Attero Recycling, joined virtually and delivered a talk on the especially important aspect of "Scope & Way Forward for India in Recovery & Recycling Critical minerals". This was followed by another distinguished speaker, Dr Nabeel Manchery, the former Secretary General, global Rare Earths Industry Association, joining virtually from Brussels. He spoke on China's Leverage & Global Rare Earths Trade. This was followed by Dr Krishnamurthy explaining "The role of Indian Rare Earths Limited in India's Critical Minerals Roadmap" and Mr Sarvanabhavan, Deputy Advisor, NITI Aayog, explaining various Initiatives taken by the Govt of India in the Critical Minerals field. Mr Manish Rathi, Vice President - Business Operations and Partnerships, Mini Mines Clean-tech Solutions, Bangalore, a special invitee for the event, explained the recent initiatives taken by the Govt of India to encourage recycling. He also explained the pioneering work being done by their company in recycling of Lithium batteries in India. The final session was the Question & Answer session. Lt Gen CA Krishnan moderated the session. The panel comprised of Dr Vasudev, Dr Amith Tripathi, Mr Pranay Kotasthane, Dr Krishnamurthy, and Mr Sarvanabhavan. Air Marshal Philip Rajkumar, Governing Board Member, Asia Centre, delivered the concluding remarks.

INTRODUCTORY REMARKS & WELCOME ADDRESS

The seminar commenced with an introductory address by Lt Gen CA Krishnan, Director, Asia Centre Bangalore, who warmly welcomed the distinguished guests, eminent speakers, members of Asia Centre and other research foundations, faculty members and students of universities and the other attendees.

The Director briefly highlighted the growing strategic importance of critical minerals in the contemporary global context, emphasising their role in economic development, clean energy transitions, advanced manufacturing, and national security. He noted that the highly concentrated and strategically sensitive nature of critical mineral supply chains has elevated these resources from being mere industrial inputs into strategic assets influencing geopolitics and national security. He underscored the need for informed dialogue and coordinated efforts to secure resilient critical mineral supply chains and set the tone for the seminar.

WELCOME ADDRESS BY MS LATHA REDDY, CHAIRPERSON, ASIA CENTRE BANGALORE

In her welcome address, Ms Latha Reddy, Chairperson Asia Centre, thanked the ICWA for jointly organising the event. She thanked the IAS Officers' Association for the assistance provided in making available the venue and related arrangements. She highlighted that the seminar is on a topic of immense importance to the country's economy, national security and its strategic autonomy. Ms Latha Reddy also extended a special thanks to the subject experts and resource persons who had taken time out from their busy schedules to participate in the seminar as speakers and invited the audience to derive benefit from their expertise.

KEY NOTE ADDRESS

Dr Nivedita Ray

Dr Nivedita Ray, Director Research, ICWA, delivered the keynote address at the seminar on Critical Minerals and Rare Earths. The speaker gave a brief introduction to ICWA, starting from 1943. She mentioned the role of bridging government and academia. ACB was mentioned as an important partner.

The address focused on the growing strategic, economic, technological, geopolitical and security significance of critical minerals in the twenty-first century. Dr Ray said that minerals have moved from being just a material input into a geopolitical issue akin to energy. The speaker highlighted emerging global and national challenges associated with their supply chains.

Dr Ray began her address by emphasising that critical minerals such as lithium, cobalt, nickel, and rare earth elements have become the backbone of the modern global economy. She underscored their indispensable role in enabling clean energy transitions, particularly in powering electric vehicles, renewable energy systems, and energy storage technologies. She further highlighted that these minerals are not limited to the clean energy sector but are equally vital for defence technologies, advanced weapons systems, aerospace applications, and national security infrastructure. Additionally, they serve as key inputs for digital technologies, semiconductors, and data-driven industries that define contemporary economic growth.

The key theme of the address was the structural vulnerability of global critical mineral supply chains. Dr Ray explained that, unlike conventional commodities such as oil and gas, critical minerals are not widely traded on transparent global exchanges. Instead, their supply chains are highly concentrated and controlled by a limited number of countries and corporations. As a result, even small disruptions in supply can have cascading effects across global manufacturing systems and defence ecosystems.

In this context, Dr Ray highlighted China's central role in the global critical minerals landscape. She noted that China dominates the extraction, refining, and downstream processing of rare earth elements, controlling approximately sixty per cent of global production and nearly ninety per cent of refining capacity.

This dominance, she stressed, is the outcome of deliberate state policy aimed at building vertically integrated supply chains. Recent Chinese export controls on rare earths and related technologies were described not merely as trade measures but as geopolitical signals reflecting the strategic leverage embedded in mineral supply chains.

Dr Ray then turned to the broader issue of supply chain vulnerabilities in an increasingly fragmented global order. She observed that the contemporary international system is marked by political tensions, economic coercion, sanctions, and intensifying resource rivalries. Drawing a parallel with historical oil politics, she argued that access to critical minerals and, more importantly, to processing and refining capabilities now determines technological leadership and strategic autonomy.

With specific reference to India, Dr Ray pointed out that the country remains highly dependent on imports for several critical minerals, including lithium, cobalt, nickel, and rare earths. In many of these categories, India is almost entirely import-dependent, creating a significant strategic vulnerability amid heightened global competition. While acknowledging that India has taken important steps through policy initiatives and international engagement, she noted that the country's approach to critical minerals is still evolving. This issue, she emphasised, is particularly significant in the context of India's Vision 2047, which places self-reliance, resilient supply chains, and strategic autonomy at the core of national development goals.

A substantial portion of the address was devoted to the role of Africa in global mineral geopolitics. Dr Ray quoted from an ICWA publication to provide details. She highlighted that Africa holds a significant share of global reserves of critical minerals, including cobalt, nickel, manganese, platinum group metals, lithium, and rare earths, accounting for nearly thirty per cent of the world[1]'s proven reserves. Despite this resource wealth, she observed that African countries capture only a limited share of value within global supply chains, as extraction is often dominated by foreign capital with minimal local processing and value addition.

Dr Ray identified this situation as a strategic opportunity for both India and the broader Global South. She argued that Africa's mineral wealth could serve as the foundation for resilient and diversified supply chains if engagement is based on genuine partnerships that emphasise technology transfer, capacity

1. ICWA, (July 2025), The Rising Significance of Critical Minerals in Africa, https://icwa.in/show_content.php?lang=1&level=2&ls_id=7499&lid=5022

building, sustainable investment, and long-term development. She also noted that African countries are increasingly resisting extractive models that perpetuate historical dependency and are instead seeking greater value addition, beneficiation, and sovereign control over their mineral resources.

The address stressed the need for a transformation in mineral diplomacy. Dr Ray argued that engagement must move beyond conventional aid or transactional investment models toward a developmental partnership approach focused on mutual benefit, shared technology, and joint industrial ecosystems. She posed a critical question to the audience: in a world where resources can be weaponised, how can supply chains be built that are secure, diversified, and grounded in cooperative development rather than geopolitical competition?

In concluding her address, Dr Ray outlined the implications for India and the Global South across three key dimensions. First, she emphasised the need to strengthen strategic autonomy by transforming import dependence into resilience through diversification, domestic exploration, enhanced processing capabilities, and recycling technologies. Second, she highlighted the importance of proactive mineral diplomacy through multilateral initiatives, e.g. the Quad Critical Mineral Initiative.

Other examples are bilateral partnerships across Africa, Latin America, and Central Asia. Third, she stressed that sustainability and ethical considerations, including environmental governance and community rights, must remain central to all engagements involving critical minerals. , , .

Dr Ray also reiterated that critical minerals and rare earths are not merely strategic resources but strategic currencies of the twenty-first century geopolitical economy. Their importance spans clean energy, defence, technology, industrial capacity, and national sovereignty. She expressed confidence that the seminar's discussions on supply chains, geopolitics, national strategies, and recycling would contribute meaningfully to India's evolving strategic thinking on critical minerals.[2,3,4]

2. Ministry of External Affairs, (02 July 2025), Factsheet : 2025 Quad Foreign Ministers' Meeting in Washington D.C., https://www.mea.gov.in/bilateral-documents.htm?dtl/39734/Factsheet++2025+Quad+Foreign+Ministers+Meeting+in+Washington+DC+July+01+2025
3. Ministry of Commerce and Industry, (06 Nov, 2025), India Deepens Trade Engagement with Latin America, https://www.pib.gov.in/PressReleasePage.aspx?PRID=2186809&reg=3&lang=2
4. Ministry of External Affairs, (06 June 2025), Joint Statement of 4th India-Central Asia Dialogue, https://www.mea.gov.in/bilateral-documents.htm?dtl%2F39643%2FJoint_Statement_of_4th_IndiaCentral_Asia_Dialogue_June_06_2025

CRITICAL MINERALS & RARE EARTHS: STRATEGIC SIGNIFICANCE & AN OVERVIEW OF SUPPLY CHAINS

Lt Gen CA Krishnan

Lt Gen Krishnan began his presentation by outlining the essentials of critical minerals, salient aspects of their supply chains, and articulating an Indian perspective. He explained how the modern world is shaped by industries such as high-tech consumer goods, digitised environment, data centres, semiconductors, AI, climate action, green energy, storage devices, electric vehicles etc. These sectors are vital to global economies and national security. Every one of these critical industries rely on a set of minerals as essential raw material inputs. These lifeline minerals possess unique characteristics ; limited or no substitutes exist currently, their mining sources are limited to a few geographies and the downstream processes from the ore extraction to refining, processing and component manufacturing have become increasingly concentrated. A handful of players dominate the entire supply chain and in some cases a single entity controls important links in the chain. This results in monopolistic control over global supplies, prices of raw materials, derivatives, and the downstream products.

Factors that make minerals ‘critical’ are their high cost and high supply risk. The list of critical minerals may vary from country to country. The list may also undergo changes from time to time due to technological advancements and new mineral discoveries. For instance, the EU’s list expanded from 14 in 2011 to 34 today. The US recently added 10 more, including Silver to its earlier list of 50 and India has a list of 24.

The speaker presented a sample list of minerals, categorised as ‘critical’ by major countries like the US, EU, China, and India. The first eight in the list, viz. antimony, cobalt, copper, graphite, lithium, nickel, tungsten and rare earths are deemed critical by all these countries. The categorisation varies from country to country in case of other minerals. Uranium and silicon were added to its list of critical minerals by the US in its December 2025 update.

To elaborate the strategic significance of critical minerals, Lt Gen Krishnan examined Rare Earths as an example. Rare Earths is a group of 17 minerals with unique names like scandium, yttrium, neodymium, dysprosium, and promethium. Interestingly, thulium (the rarest Rare Earths) is about two hundred times more abundant than gold, and cerium (the most abundant Rare Earths) is about 15,000 times more abundant than gold.

However, rare earths occur in small, dispersed quantities, often mixed with radioactive elements such as uranium and thorium, making economic extraction challenging due to complex separation processes and environmental concerns.

In 2024, global production of Rare Earths was about 400,000 metric tons, with China contributing almost 70%, the US 11%, Myanmar about 8% (mostly illegal), with India and Russia contributing under 1% each. China also holds largest global rare earths reserves with 44 million metric tons. Though extractions lags in India, it holds the third highest reserves of about 7 million tons.

He went on to explain how rare earth elements have assumed immense importance in the 21st-century global economy. These minerals form the backbone of modern hi-tech industries, technologies that support clean energy systems, aerospace and defence industries etc. They have become strategic resources at the intersection of economic growth, technological advancement, and national security. Rare earths are indispensable performance enhancers in high-tech industries worth billions of dollars. They are used in small quantities, but have almost no substitute at present. Their applications span fighter jets, ballistic missiles, electronic displays, radars, oil refineries, GPS, automobiles, mobile phones, fibre optics, ceramics, and jewellery. They also serve in nuclear reactors as control rods and neutron absorbers, and are crucial for green technologies like electric vehicles, wind turbines and LED lighting.

The single largest use of Rare Earths is in making powerful, lightweight permanent magnets, found in laptops, phones, and almost every electronic device of everyday use. Till very recently, the US defence industry was using about 400 Kg of China sourced Rare Earths for every single F-35 frontline fighter jet, while the DDG-51 destroyer required 2,500 kg, and each USS Virginia-class submarine used over 4,000 kg.

Every mobile phone requires Rare earths, albeit in small quantities. With over 7.5 billion smartphones in use (projected to exceed 8 billion by 2028) and 1,400 million new ones entering the market annually, no respite is likely in the demand for rare earth. For the clean energy sector, rare earths are even more critical.

Every important component in an electric vehicle relies on rare earths. The most critical are its numerous electric motors. Similarly, a 3-megawatt wind turbine requires 2 tons of Rare Earth permanent magnets. This overview of the spectrum of rare earth's application exemplify the huge dependency of modern high-tech industries on such minerals.

Shifting to the Indian context, the speaker highlighted India's position as the fourth-largest economy, surpassing Japan and just below Germany, poised to advance further. In purchasing power parity (PPP) terms, India ranks third at $15.7 trillion. Projections indicate India set for a 2x GDP jump in about 15 years and 3x jump in about 25 years. He argued that this timeline needs to be viewed as a near-term reality in the Indian context, given India's average age of 29. India's impressive projected growth, however, would imply huge spikes in energy consumption as well as carbon emissions. Comparative data shows India's per capita GDP in 2025 at about $11,000 (45% of the world average), with both per capita electricity and energy consumption at just 40% world average. As a country, India ranks third in total energy consumption and carbon emissions, behind China and the US, despite India's abysmally low per capita energy consumption as well as its very low per capita carbon emissions.

He highlighted that while India's energy consumption must undergo significant rise over next few decades, the country cannot afford to let the required 2x- 3x jump in its energy consumption result in corresponding emission jumps. This makes green transition an absolute non-negotiable for India.

Climate Goals: India has set ambitious climate goals, including net zero by 2070, and increasing non-fossil capacity from the present 262 gigawatts to 500 GW by 2030. India's renewable energy targets aim to more than double its solar and wind power generation capacity by 2030. During the decade post-2030, India needs to make a 3.5x capacity jump by 2040 in order to meet its net zero goal. The country is well on track to meet and even exceed these targets. But we need to understand that these ambitious climate goals will witness huge spike in India's demand for green tech materials, creating new supply chains and dependencies. As an aside, Lt Gen Krishnan explained that the global semiconductor focus relies on high-purity silicon (also needed for solar panels), gallium, and germanium.

Having explained the non negotiable need for a vigorous push for green transition in the decades ahead, he examined the critical green energy minerals of copper, lithium, nickel, cobalt, graphite and silver. Even in the modest climate action scenarios, the demand for these minerals will double in 10 years.

In the case of sustainable climate action scenario, the demand spike will be 2.5 to 3 times. As nations transition towards green energy and digital economies, critical minerals have moved beyond the realm of industrial inputs to become instruments of geopolitical influence and national power.

Resource Geography: Lt Gen Krishnan brought out that the supply sources of most critical minerals are concentrated; 70% cobalt comes from mines in DRC, 50% nickel comes from Indonesia, 50% lithium from Australia, 60% graphite from China, 70% platinum from South Africa and 45% palladium comes from Russia. Ownership of mines across the world shows China's stakes across continents, especially in Africa for cobalt and nickel. Refining process is another critical dimension of the supply chain which is dominated by China ; over 90% for graphite and rare earths are refined in China. China also accounts for refining 90% of the global manganese, 80% cobalt, 70% lithium, and half the global copper. China leads in production of germanium, zinc (accounts for one-third global supplies), steel, gold, coal, magnesium, aluminium, tungsten, tin, molybdenum, titanium, and bismuth.

Coming to the significance of downstream supply chains, he explained the dependency of Electric vehicles on green technology minerals with facts and figures. From mining the minerals needed for Electric vehicles to processing and refining them to making chemical compounds to manufacturing components such as battery cells to making EV batteries to making the final EVs themselves, the entire supply chain is dominated by China. Lt Gen Krishnan further explained the dangers of this monopoly in the backdrop of the projected supply shortages of important EV minerals by 2030 ; the projected shortages by 2030 are in the range of 40% supply shortage for cobalt, 30% for lithium, nickel 15%, copper 10%, and shortage in silver supply 30%. Naturally, this could end up in tariffs, restrictions and intense geopolitical tussle. He further highlighted the significance of the supply shortages by explaining that the average time taken globally, from the time a mineral discovery is first made to setting up of a mine and mineral production from the mine is about 12 to 15 years.

China's control over the global Critical Minerals supply chains is clearly evident. However, he explained that it is possible to find alternate sources and establish secure supply chains through international cooperation. It was also flagged that what the US is doing under President Trump does not augur well for fostering such cooperation.

Lt Gen Krishnan concluded by stating that for a country of India's scale, population, and economic ambition, strategic self-reliance in critical minerals is not optional but an imperative. While acknowledging that global cooperation and diversification of supply chains must be pursued, he stressed the need for concerted efforts to explore and utilise India's own untapped domestic mineral resources by focusing on long term planning, formulating a facilitating policy framework, encouraging private participation and creating public awareness.

DYNAMICS OF MINING, MINERAL PRODUCTION & WHAT INDIA CAN DO

Dr V. N. Vasudeva

Dr V. N. Vasudeva began his talk by framing it as a "story within 25 minutes." He introduced the periodic table, noting that 85 per cent of the metals in it come from the earth, while the rest are from air. He explained that the concentration of these metals to a mining level is typically handled by geologists. He emphasised that every material used in daily life has its roots in the earth. He referenced a list of critical metals useful for defence purposes mentioned earlier by Lt Gen C.A. Krishnan. Dr Vasudeva highlighted various minerals used in the kitchen, such as cutlery and crockery, including clay, quartz crystals, chalcopyrite, bauxite, and halite. He extended this to the construction of highways, which requires iron ore, manganese, chromite, limestone, and other materials.

He listed applications in iron, steel, steel alloys, electrical and electronic gadgets, power generation, nuclear energy, glass, ceramics, cement, talcum powder, and even materials for medicine production—all sourced from the earth. He noted

India's latest defence military modernisation budget of 79,000 crores, which places a huge demand on minerals[5].

The speaker discussed the categorisation of mineral deposits into bulk and non-bulk minerals. Bulk minerals include lignite, bauxite, coal, limestone, manganese, chromite, and magnesite. Non-bulk minerals (NBMs) encompass all critical minerals, base metals, and precious metals. He stated that India's resource potential in bulk minerals is very good. The GDP is forecast to increase, with the mineral contribution to GDP expected to rise to 2.5% next year. This reflects the mineral sector's centrality to manufacturing competitiveness, energy security, clean energy transition, and employment generation[6].

For non-bulk minerals, including critical minerals, base metals, and precious metals, India's position is one of dependency. For gold, India has abundant geological resources but produces only 2.2 tons annually while importing nearly 900 tons, ranging from 500 to 900 tons over the last 35 years[7].

He remarked that India is already a 6 trillion dollar economy if considering the 25,000 tons of gold in households as jewellery, rather than a 5 trillion dollar economy. He urged converting these resources into producing mines. He referenced a geological map of Karnataka, showing yellow dots and circles as proven resources by drilling, with an inventory held by the Geological

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5, Centre clears Rs 79,000 crore defence proposals to enhance capabilities of Armed Forces, https://www.newsonair.gov.in/defence-acquisition-council-clears-proposals-worth-%E2%82%B979000-to-enhance-capabilities-of-armed-forces

7. DGCI&S, Ministry of Commerce & Industry Commercial Intelligence (CI) Division April 2022 to March 2025, Navigating India's Gold Import Trends, https://www.dgciskol.gov.in/CI_Analytical_Reports.aspx

Survey of India and state mines. He stressed the need to convert these resources into reserves and mines.

For uranium in India, there are numerous explored places with proven resources, but only three mines are currently operating. He discussed Indian nickel, platinum group elements, and critical minerals distribution. He asserted that if any country can challenge China in rare earth elements, it is India[8].

He offered to show resources in books during the discussion and stated that only India can take on China. He mentioned the distribution of rare earth elements, to be discussed by his friend P. Krishnamurthy in the later session. He mentioned a good book highlighting India's position in rare earth elements, authored by Dr P Krishnamurthy[9].

Dr Vasudeva explained how mineral discoveries happen ; resources are identified and explored, quantified, graded, and certified for commercial mining and metal production. The exploration process follows an evidence-driven path from green field to mineral discovery, mineral prospect, initial drilling for mineral resource, feasibility studies, and finally to commercial mining and mineral production.

He offered his entire slides for distribution and skipped the details for time and explained the process from regional exploration (e.g., 5,000 square kilometres) to a mining area of

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8. ScanX, (25 Dec 2025), India's Household Gold Holdings Cross $5 Trillion, Exceed Country's GDP at Record Prices, https://scanx.trade/stock-market-news/commodities/india-s-household-gold-holdings-cross-5-trillion-exceed-country-s-gdp-at-record-prices/28527458
9. Krishnamurthy, P., (2024), Rare Earth Element Occurrences and Deposits of India and Strategies for New Discoveries, Geological Society of India

about 5 square kilometres. Organisations like the Geological Survey of India and state departments engage in this process.

For example, reducing a 1,000 square kilometre area to 5 or 1 square kilometre for mining involves studying literature, geological maps, geophysical data, spectral images (hyperspectral data), discussions with geologists who worked in the area, preliminary field visits, selecting the target area, and stage-wise exploration.

He noted that it is now easier to narrow down areas using desktop studies and satellite-based data, including data from ISRO. Twenty years ago, he recalled buying hyperspectral data from the United States Geological Survey and processed it in Bangalore under a company started by Mr Charles Edward Devenish.

Geophysical data includes aero geophysics and ground geophysics, with varieties that are metal- or mineral-specific. Processing this data narrows targets before drilling to prove resources. Structural analysis is used to locate mineral deposits precisely. Panning for gold is one of the easiest and oldest methods, with India having nearly 900 locations. India has been panning for gold for almost 8,000 years. He mentioned his work in Chhattisgarh, parts of Madagascar, and Jharkhand (where they are called Jalgarth or Sonjharias), using GPS to spot locations, record them, and trace gold origins to primary areas of mining interest.

Soil sampling was exemplified from the Kolar gold fields: systematically recording locations, collecting samples, and processing to identify high anomalies (high concentrations of elements) for detailed exploration involving trenching and drilling.

Field clues for geologists include green malachite (copper hydroxide) in weathered zones, brownish iron sulphides, or oxides like pyrite or pyrrhotite, and rare specks of gold (exaggerated in photos for illustration), which help identify primary sources. These are earth surface clues for mineral deposits. Added clues include ones in the Hatti gold mines—scheelite (tungsten) luminescence under UV lamp.

Next steps include rock chipping and channel sampling to precisely record limits of metal or mineral areas. For a boundary demarcated in white line (e.g., 1,000 square kilometres), exploration may yield four targets for drilling to confirm subsurface presence. He referenced drilling at Jonnagiri, India's first full-fledged private sector gold mine, processing 1,000 tonnes a day. Bedded deposits are drilled to find subsurface extension; vein-type deposits are drilled accordingly[10].

India is capable of drilling up to 1.5 kilometres (achieved 10 years ago in Rampura, Rajasthan area) depth. Drilling 300 to 500 meters is routine now. After data collection, modelling involves creating cross-sections for depth, width, and length, then 3D modelling of resources. Mine modelling uses the past three years' market prices to determine grams per tonne of ore, mining costs, and ensure 15-20% profit after expenses. Feasibility studies begin with resource modelling.

The entire process goes from a greenfield (unknown or little known) to the brownfield or mining stage. Simultaneously, it is also examined and analysed if the mineral or metal can be extracted; if not, exploration may be called off. Successful exploration passes through numerous stages of value addition.

In one sense, exploration is a real estate program: at every stage of exploration, value is added. From reconnaissance to mining, value increases at every step. A company can pass on the project at any stage (e.g., after initial reconnaissance) to another for drilling. Exploration involves enormous risk, and if played thoughtfully, it becomes a value addition program.

Dr Vasudev discussed the original sources of metals and their concentration in the Earth's crust. All periodic table metals are linked to the Earth's origin and differentiation into crust, mantle, and core. Metals are confined to the top 20 kilometres of the Earth and span the entire earths surface. Finding where the nature has gifted concentration is the geologist's business.

Volcanoes bring metals up; wherever there are volcanoes, there are metals. Magma brings them to the upper crust. Volcanoes are the conduits. He mentioned visiting Lake Abbe at the Ethiopia-Djibouti border which has abundant sulphur, hot springs, and metal deposits, including critical metals.

In Karnataka, greenstone belts (volcanic belts) indicate volcanoes before 2.6 billion years ago (260 crore years). There were submarine volcanoes and seas with full evidence. Volcanoes contributed gold and other metals near the surface.

Basins of deposition and volcanism are folded and fractured; metal-bearing fluids concentrate near the surface in the first 2-3 kilometres. Kolar gold field reached 3.2 kilometres in the 1960s -70s (first in the world). Others include Ashanti in Ghana (3 km), Elona in Andhra Pradesh, Canada (close to 3 km).

The Witwatersrand gold fields near Johannesburg are 4.2

kilometres deep, still yielding gold. The processes of volcanism, sedimentation, deformation, and metal-bearing fluids concentrate metals at the surface.

He highlighted policy challenges in India's mineral sector, referencing a 2017 article titled Why skewed policy keeps foreign miners away from exploration? which criticised the failure of existing acts and rules to advance the non-bulk mineral sector[11].

To conclude, Dr V. N. Vasudeva wrapped up by reiterating the persistent policy failures in India's non-bulk mineral sector (including critical minerals), despite bulk minerals' strong contributions to GDP and employment. He criticised the shift from the First Come, First Served (FCFS) system (in place from 1958 to 2012) to the auction-focused licensing under the MMDR Act 2015 amendments and the 2019 National Mineral Policy[12,13] .

Arguing that auctions deter exploration, especially for large areas. In this regard, he further reiterated his ongoing advocacy, including testimony with colleague Mr Charles Devenish before the Parliamentary Standing Committee and a recent interaction with the Ministry of Mines. He urged changes to fast-track non-bulk metal discoveries.

10, Jonnagiri Gold Mine, https://geomysore.com/mining.php

11. Business Standard, (15 June 2017), Skewed policy keeps foreign miners away from exploration in India.
Gazette of India, (26 March 2015), The Mines and Minerals (Development and Regulation) Amendment Act, No 10 of 2015,

12. Gazette of India, (20 May 2015), Mineral (Auction) Rules, 2015 https://nmet.gov.in/content/innerpage/page.php?id=95

13. Ministry of Mines, (2019), National Minerals Policy 2019, https://mines.gov.in/webportal/nationalmineralpolicy

GEOPOLITICS OF CRITICAL MINERALS

Pranay Kotasthane

Mr Pranay Kotasthane noted that two excellent speakers have preceded his session. He explained that his talk would focus specifically on the geopolitics of critical minerals and serve as a provocation, potentially contradicting some earlier points. He invited the audience to discard any views they disagreed with, while offering a perspective grounded in historical instances of how the geopolitics of critical minerals has played out. Mr Kotasthane clarified the scope, stating he would not discuss India extensively as he would concentrate on his sub-topic, geopolitics of critical minerals. He outlined the structure; first presenting his core argument, then discussing "materials myopia" (an idea present for decades), explaining how it has returned, its meaning, and its fallouts, followed by case studies, and concluding with takeaways.

Core Ideas: He provided a bottom-line-up-front summary of his three core points. First, not all critical minerals are critical in the same way; even from a geopolitical and leverage perspective, they vary significantly, and geopolitical leverage is often overestimated. Second, China's geopolitical leverage, based on its dominant position in critical mineral supply chains, is overestimated. Third, substitutes and alternatives being developed worldwide are underestimated. He hoped to convince some in the audience of this argument.

Strategic Minerals: He then turned to materials myopia. He noted that General Krishnan had already touched on this, but added a nuance, definitions of critical minerals differ by country and are geopolitical terms. Russia and China use “strategic minerals” rather than “critical minerals”,. This might innocently reflect importance to strategic industries, but the term “strategic” could also imply potential use as foreign policy levers[14.15] .

USA Definition: In contrast, most countries, such as the United States (via the USGS and National Research Council), define critical minerals as non-fuel minerals that are essential in use (with broad applications), non-fuel (not burned up like oil), and subject to supply risks (geologic, technical, environmental, social, political, and economic). Countries map these risks to create lists, making both the definition and terminology contested. To illustrate, he referenced a USGS chart showing US import dependence for various elements. He liked the chart because it demonstrated how these minerals are critical in diverse ways, much like water for human survival, but applied differently.

Examples included elements in night vision goggles and in communications/global positioning systems, where the US produces little and is largely import-dependent. Brown numbers/

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14. Russian Government Order no. 1838-r, ***‘Strategy for the Development of the Mineral Resource Base of the Russian Federation to 2050,*** 11 July 2024, section II (author translation).
15. Chinese Government, ***Outline of the 14th five-year plan for the national economic and social development of the People’s Republic of China and Vision 2035,*** 12 Mar. 2021.

columns indicated high import reliance for most elements, underscoring broad dependency even for the United States[16].

Weaponisation: He emphasised that the weaponisation of materials is not new. In the 1930s, rubber was a strategic material and a classic dual-use good essential for tanks and military purposes, produced mainly in Southeast Asia. During World War II, Japan occupied rubber-producing areas, causing shortages[17] . The response was synthetic rubber, discovered in 1908–1910 but underutilised until geopolitical urgency drove investment; it eventually became widely available, reducing rubber's strategic importance. In the 1950s, during the Korean War, Mercury was critical for walkie-talkies, but alternatives overcame the shortage[18].

Materials Myopia: The term Materials Myopia originated in the 1980s from a US Congressman, amid a similar situation: the USSR and its allies dominated production of key minerals (high US import dependence on cobalt, manganese, chromium, platinum—the "big four"). Fears arose of supply cuts. A real disruption occurred when DRC rebels occupied cobalt mines (cobalt used in jet engine super alloys), raising fears of an "oil shock" like 1973. No major shock ensued because of military stockpiling under Reagan, substitutes (molybdenum, carbon fibres, composites), and high prices enabling new mines in safer locations like Australia and Canada. Low prices from

16. National Research Council (NRC), **Minerals, Critical Minerals, and the U.S. Economy,** 2008
17. Baums, Ansgar, and Nicholas Butts. 2025. **Tech Cold War: The Geopolitics of Technology,** Lynne Rienner Publishers, Inc.
18. J. Zhou and A. Månberger, **Critical Minerals and Great Power Competition: An Overview,** SIPRI, October 2024, https://doi.org/10.55163/WEMJ9585.

Chinese flooding had previously deterred investment; higher prices spurred recovery. From these cases, he drew a lesson from the politics of innovation literature (citing Mark Taylor's book): when external threats exceed internal divisions ("creative insecurity"), nations invest in innovation. Examples include rapid COVID-19 vaccine development. China has created such insecurity today, accelerating global innovation empirically[19].

Contemporary Scenario: He then shifted to the contemporary situation over the last 20–25 years. Spain introduced a priority minerals list in 2002, but momentum grew after the 2010 Senkaku Islands dispute, when China surreptitiously restricted rare earth exports to Japan (not openly declared). Countries realised this could affect them and began creating lists. Today, over 20 countries have them (likely more recently). The US 2022 list had 50 elements (now around 60); India's has 46 (including 17 rare earths). He critiqued that deeming ~40% of the periodic table critical dilutes the concept[20] —if everything is critical, nothing is—and urged focusing on fewer priorities.

Oil vs Critical Minerals: He distinguished critical minerals from oil: oil is consumed as fuel, causing economy-wide inflation from blockades; critical minerals are recyclable, with small quantities enabling stockpiling (unlike oil's limited reserves). Restrictions (e.g., gallium/germanium since 2023) have affect specific industries, not an economy wide inflation.

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19. Taylor, Mark Zachary. 2016. ***The Politics of Innovation,*** Oxford University Press
20. Royal Decree 647/2002, of July 5, declaring the mineral raw materials and related activities, classified as priority for the purposes of the provisions of Law 43/1995, of December 27, on Corporate Income Tax., https://www.boe.es/eli/es/rd/2002/07/05/647/con

Critical Minerals can be stocked in reserve. Many countries have stockpiles, and joint stockpiles are discussed.

Supply Chain: He described an abstracted supply chain: extraction/mining → processing/refining → components (e.g., rare earth permanent magnets) → end-use (e.g., PMSM motors) → products. Opportunities include recycling, new efficient technologies, and substitutes (e.g., Tesla's upcoming non-permanent-magnet cars, similar moves by Indian two-wheeler firms; alternatives like ferrite magnets or induction motors, with trade-offs).

Dragon in the Room: Turning to China, he likened its dominance in rare earth processing to Taiwan's in semiconductors, polluting processes shifted there over decades, leading to >2/3 production and >80% processing of rare earths. Yet China has dependencies (>70% import reliance on copper, lithium, nickel, titanium, cobalt; importer of RE concentrates). Refining technologies originated in the West and can be relearned. Dominance stems from structural overcapacity (high investments, export focus, low prices), making others uncompetitive over 10–15 years.

Recent weaponisation differs from 2010's covert approach: now explicit and structured (commerce ministry licenses). The USA had restricted controls on China in semiconductors, which China is replicating in critical minerals. The world expects restrictions (e.g., recent dual-use curbs to Japan). October 9, 2025, saw a major expansion: seven new controls (six materials-related), high-end battery approvals, a de minimis clause (foreign firms in China need permission to trace Chinese rare earths). Licensing has been extended to smelting, separation, magnets, super hard materials, synthetic diamond, single crystals, wire saws, and grinding wheels. They are used in industries besides defence. Expanded to 12 rare earth elements; January 2026 targeted bans to Japan, e.g. indium compounds, antimony, graphite, tungsten)[21].

Global Responses: Other countries respond in four ways: Material substitution e.g., LFP batteries over cobalt-heavy ones; System Substitution (e.g., lithium-ion to hydrogen fuel cells for trucking); Process substitution (recycling/urban mining, with incentives in India's National Critical Mineral Mission); and Efficiency improvements (less material use in designs).

Response Framework: Mr Kotasthane stressed technology dependence does not always mean strategic vulnerability, e.g., gallium/germanium restrictions had limited impact; others can catch up as costs/policy barriers ease.

He presented a framework for denial, use secondary sanctions, labour restrictions, export/end-use controls, outgoing investment curbs; for outpacing, build partnerships (e.g., Mineral Security Partnership—MSP, 14 members including India[22] —to shorten timelines from IEA's 16.5-year average), indigenization, offsets, equity investments, upfront capital, price guarantees; to counter price suppression, encourage substitutes; Remove bottlenecks, speed approvals, partnerships, stockpiling effective for small-quantity minerals.

21. Reuters, (Jan 2026), Japan condemns China's dual-use export ban as rare earth curbs loom, https://www.reuters.com/world/asia-pacific/japan-says-chinas-dual-use-export-ban-unacceptable-rare-earths-crosshairs-2026-01-07/
22. Mineral Security Partnership, https://www.state.gov/minerals-security-partnership

He noted MSP catalyses investments (19 projects in upstream mining, recycling, midstream processing), joint stockpiles, and long-term substitution research. Finally, he turned to lessons from 2010 rare earth restrictions: Japan sought substitute sources and built stockpiles.

FUTURE TRENDS AND TECHNOLOGY IN MINING & GLOBAL INITIATIVES IN CRITICAL MINERALS AND RARE EARTHS

Dr. Amit Tripathi

Dr Amit Tripathi introduced himself and stated that he was there to take the audience on a journey to a frontier of one of the world's oldest industries. He explained that they were going to explore how data was becoming more valuable than the ore itself and why this invisible revolution was a matter of urgent global strategy.

Sensor Driven Mining: He invited the audience to close their eyes and imagine a mine, asking what they saw—deep dark tunnels, dust, dynamite, and diesel. He described that as the story of the past. He then said that he wanted to show a different picture—one where the most valuable tool was not a pickaxe but an algorithm, and where the most important discovery was not made by a geologist's hammer but by a satellite's sensor. He declared that they were witnessing the dawn of an invisible mine:

an interconnected asset or an intelligence-driven operation that was becoming critical not just for profit but for national security.

To understand the future, he stressed, they must see the whole chain, and the whole chain did not start midstream; it started right at the beginning. From finding the mineral to producing pure metal, each step had historically been defined by physical labour and gut instinct. But a profound shift had occurred. He emphasised that this was no longer just an extractive industry; it was an information business.

Difference between Exploration and Mining: He clarified that the mining business and upstream exploration were very different. The exploration business was like a tech startup; it had nothing to do with the mining industry, created raw material for the mining industry, and thrived in a remarkably different regulatory environment than a mining business. Therefore, it needed a different policy framework, which unfortunately did not exist in India at the time. He added that a few of his comments came from having had very little opportunity to work in India. While being Indian, he had an outsider's perspective on how things worked in India. He had worked in 40 different jurisdictions with different laws, and there were positives and negatives everywhere.

SATINT: In the era of geopolitical tensions and supply chain fragility, he said, controlling this intelligence process was not just profitable; it was a core component of national security. The minerals in one's smartphone were as valuable as the oil in a tanker. He explained that legacy reconnaissance meant geologists working for years, often hindered by terrain and bureaucracy.

Now, he suggested thinking bigger: they deployed hyperspectral and geophysical sensors on satellites, aeroplanes, or helicopters. This is SATINT, which acted like a high-tech mineral sniffer. Every mineral reflected light uniquely and had a unique physical property.

These sensors captured the fingerprint, allowing scanning from orbit and from the sky to identify the fingerprint of mineral deposits, which is now possible to scan an entire country and prepare a Digital Prospectivity Map. This, he said, was the ultimate strategic asset—a nation knowing exactly what it had and where the wealth lay in its soil without the initial political friction of ground access.

Case Study: He referred to data shown on the screen as an actual case study. His company had been involved in a reconnaissance project over a very large 13,000 square kilometre area to identify critical minerals, focusing on nickel, and they had finished that project in three months. A 13,000 square kilometre area typically should take a couple of years, but they had been able to finish it in three months. That was about two years earlier; now they had expanded their capability and could probably do it in one month.

With a map of potential, he continued, the data was overwhelming, full of false positives and geological noise. This was where the geo interface came in—the modern artificial intelligence technology they were developing in-house. It was not a mysterious black box; it was a digital geologist that worked with humans. They did not replace humans; they worked with humans. He shared his favourite analogy: The stealth bomber was invisible to traditional radar, and minerals were buried under rock and soil. This AI was the new radar that pierced the camouflage, filtered the noise, and revealed subtle bullseye signatures of ore bodies. The result was that discoveries that once took decades now took years. As General Krishnan had shown, he noted, the typical time from greenfield to a mine was around 16 years, with a large part of that being the discovery phase, and this was where they came in. They had case studies where they had been able to reduce this initial discovery time—which was typically eight to nine years—to three to four years. This reduction in time typically increased the project NPV by 35%. Once they had found something valuable, he moved on to the feasibility part. The critical question was whether they should actually build a mine there. Historically, feasibility studies were like thousand-page reports of a tombstone that were outdated by the time they were prepared.

Digital Twin: Today, he said, it was a living digital twin—think of it as a flight simulator of a mine. They built a one-to-one replica and tested it against the world. They could simulate a trade war, a hurricane, a price crash, or what Trump's next policies would be. Then they quantified the eight pillars of a mine: two technical (geology/resources and metallurgy) and six non-technical (environmental, social, market, cost, jurisdiction, and infrastructure). All this, he explained, told the investor exactly what the mine was and told the government how to design a stable taxation policy for a particular project. Each mine and each project were like fingerprints—they were different and required different substrates to be effectively profitable and produce resources for a long time. This prevented multi-billion dollar stranded assets. He deferred to Mr CEE Devenish that he had been struggling with this for over two decades, but now he had gotten over the hurdle, and he hoped much more would pass the hurdle. The digital twin also enhanced not just profit but compliance and safety. The digital simulation stress test was a perfect way to manage tailings storage facilities to prevent collapse disasters.

Autonomous Machinery: He then described imagining a site operating 24/7 in a remote, harsh environment, but looking closer, there were no people in the pit. Autonomous haul trucks guided by a central artificial intelligence brain moved with very efficient silence. Predictive maintenance models warned of failures before they happened. In a city a thousand miles away, a technician sitting in an air-conditioned office could monitor from a distance. This was the interconnected asset. It was safer, more productive, and more consistent. It also solved the human resource crisis, allowed operation in places where they simply could not before, and dramatically reduced the environmental footprint through precision. This future was not without perils, he warned. They were building incredibly complex connected systems. The number one challenge was making all the tech talk to each other: satellite data must flow seamlessly to the geologist's artificial intelligence, which must flow seamlessly to the mining engineer's digital twin, and that should flow the command precisely to the haul truck. This integration created a single point of truth but also a single point of failure. Cybersecurity was now a physical safety issue—a hack could stop a nation's critical mineral supply.

Skill Set: The talent they now needed had changed: they were recruiting hybrid minds that could understand the ore and the rock but could also understand Python code. This was not science fiction; this was happening now, led by bold innovators worldwide. In Australia, Fleet Space used satellite and seismic sensors for real-time 3D imaging. In Canada, the company Novamera practised surgical mining—they put hyperspectral sensors on short-hole tips and extracted ore with pinpoint precision, leaving the waste behind. In India, AI resource exploration was integrating multiple platform data for three-dimensional prospectivity mapping. They were right then in the process of providing this three-dimensional prospectivity mapping to companies in Canada and the US, and those companies were optimising their drill programs based on these reports. The cybersecurity frontier was the next great arms race in the industry. These pioneers were proving that the future was not uniform; it was a tapestry of specialised technologies moving together, and interconnectivity was the key.

Zooming out, he explained why all this mattered: the invisible mine transformed the industry from a simple supplier of commodities to a foundation of sovereign capability. It provided strategic foresight—knowing what you had—built economic resilience by de-risking projects, and ensured operational sovereignty—control over your own destiny. In the race for energy transition and technological supremacy, data was the new uranium, and the nation that mastered this intelligent value chain held a decisive invisible advantage.

Global Examples: He then moved to the second part of his presentation: global initiatives in critical minerals and rare earths. They had seen the technological revolution inside the mine; now they should step back and see the battlefield upon which this revolution was playing out. They had moved from an era of globalisation, where efficiency was king, to an era of weaponised interdependence, where supply chains were strategic weapons. Looking at recent developments, he asked why Trump had imposed punitive tariffs on India but could not on China.

PRC: China had retaliated with a magnetic export restriction, and the US had been forced to retreat—it had just happened. But the tariff stayed on India; he did not have leverage. More recently, just last week, China had imposed silver export restrictions and spooked global markets. He would not go into the details of silver because Pranay had already given great detail on why silver was critical. The fundamental truth of the 2020s was that a nation's GDP and its defence readiness were now components.

For critical minerals, especially rare earths, China did not just have a lead; it had a commanding monopoly over the midstream. Think of it as controlling the only refinery for a vital fuel. This was not theoretical—they had already weaponised this position. The response from the West and allies had been a frantic effort to de-risk and friend-shore. But building a parallel universe of processing plants from scratch was a monumental task. It required staggering capital, technology that they had acquired, and human capital that did not exist yet. To navigate this, one must understand both China's strengths and surprising vulnerabilities. The strength was an integrated state-driven fortress, but its Achilles' heel was upstream: it was critically dependent on unstable Myanmar for the heaviest, most important strategic rare earths. He suggested reflecting on how the Chinese strengths and the Indian strengths were different. Chinese strength had always been a state centrally controlled narrative. Indian strengths were their people, diversity, and diaspora. They should not look to replicate the Chinese model but work on their strengths.

Furthermore, the Chinese strategic lead was based on old dirty chemistry, and its classic tactic of flooding the market to bankrupt competitors was now being met by Western price floors and minimum support prices for minerals. More strategically, by signalling an export cliff of late (perhaps referring to past actions), and they had signalled November 2026 as an export restriction. China had inadvertently given its rivals a tactical window to act.

Global Response: Faced with weaponised interdependence, the democratic world was not just reacting; it was architecting a parallel universe. The goal was explicit: build a China-free supply chain for the most critical components. This was being executed through two powerful complementary alliances. Pranay had already spoken about the Mineral Security Partnership—it was not a club; it was like a geopolitical block. Its sole purpose was the security of supply. It used state capital and policy to de-risk projects, ensuring the minerals for a fighter plane or submarine could not be turned off by a foreign adversary. The second was the Quad Critical Minerals Initiative—this was a theory in its practice. It leveraged the unique symbiotic strengths of four key democracies: Australia's rocks, Japan's refineries, America's wallets, and India's hands and markets. Together they formed a complete, resilient loop. This was the operational blueprint for decoupling. One of the most elegant strategies was not to fight the fortress head-on but to go around it.

What if you did not need the rare earths at all? Automakers were already doing this—as Mr Pranay Kotasthane mentioned, Tesla and Toyota were also doing that. The US was betting big on iron nitride, a material that could disrupt the entire magnetic landscape. It had advantages and disadvantages, but it was a major upcoming technology. This was the power of innovation—it could turn strategic dependence into a historical footnote.

But China was not standing still; they were evolving its strategy. They were moving to control entire life cycles—from mine to factory to discarded phone—and putting them back into the supply chains. By setting global recycling standards, they aimed to lock in technological dominance for decades. And please keep watching silver—they were rehashing the old choke point. This marked a critical escalation from mineral advance to knowledge advance. The message was stark: if you did not master the underlying science and standards, you remained perpetually vulnerable.

Indian Response: For nations like India, this made domestic R&D in metallurgy and material sciences not just an economic option but a national security imperative. There was no room for delay. Bringing this home, he asked how India was responding—not with a single policy, but a five-point playbook for strategic autonomy[23].

First was a National Critical Minerals Mission. It drove innovation, targeting patents and turning industrial waste like fly ash into a national resource. Fly ash was another resource for rare earths that had so far not been mentioned there, so he wanted to discuss it a bit. Fly ash did contain rare earth elements; it came from coal, and after burning the coal, it stayed in the ash. There were technologies, but it needed a lot more focus to

23. Press Information Bureau, (02 Feb 2026), India's Rare Earth Strategy: Manufacturing, Corridors, and Global Integration, https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=157165&ModuleId=3&reg=3&lang=2

develop. And they had plenty of it[24] —they had mountains of it lying unused.

Secondly, through Khanij Bidesh India Limited (KABIL), India practises resource diplomacy, securing captive mines abroad. It was not just an investment; it was prepositioning of supply lines. But there were some very critical weaknesses in KABIL. Why was KABIL not thinking of partnering with India's strengths[25] —India's private sector and diaspora? They went out and did government-to-government contracts. Outside India, there were no public sectors; all mining and exploration was done by private players. KABIL was hesitant to engage.

Third and crucially, the Rare Earth Permanent Magnet scheme has recently been approved by the Union Cabinet,. This was about sovereign defence by building capabilities so that the critical magnet at the heart of the BrahMos was sourced, produced, and manufactured entirely within their trusted ecosystem[26, 27]

Fourth, he thought there was going to be greater discussion on urban mining, which recovered gold, cobalt, and rare earths from e-waste already within their borders. It was estimated that

24. Ministry of Mines, (Jan 2025), National Critical Mineral Mission, https://mines.gov.in/webportal/content/national-critical-mineral-mission, https://www.pib.gov.in/PressReleasePage.aspx?PRID=2120525&reg=3&lang=2
25. https://kabilindia.in/
26. Press Information Bureau, (26 Nov 2025), Cabinet Approves Rs.7,280 Crore Scheme to Promote Manufacturing of Sintered Rare Earth Permanent Magnets (REPM), https://www.pib.gov.in/PressReleasePage.aspx?PRID=2194684&reg=3&lang=2
27. Press Information Bureau, (27 Dec 2025), Powering India's Next Tech Leap through Rare Earth Permanent Magnet Manufacturing Ecosystem, https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=156753&ModuleId=3&reg=3&lang=1

they could recover about 40,000 tons of critical metals from the smartphones they threw away.

Fifth, they built a 90-day national stockpile. This was their financial and strategic shock absorber against the export cliffs they had discussed.

Emerging Roadmap: Recapping and coming back to one of the earlier slides, the roadmap was clear: they must intelligently unlock their own geology, secure resources globally, dominate key manufacturing stages like magnet production, and lead the world in recycling technology. All this had already been said. The ultimate lesson of this new mineral age was that strategic power was no longer from owning the resource but from controlling the most resilient and technologically sophisticated value chain around it. But they did not necessarily need to be reactive.

Reconnaissance: Returning to the mineral industry value chain, it started with reconnaissance. Not investing here meant the discovery tap remained shut, and downstream industrial growth would remain import-dependent and vulnerable. It was like trying to water your lawn while stepping on the pipe. They did not have any investment in reconnaissance now. He also recapped the eight pillars of a mine: resource, metallurgy, environment, social, market, cost, jurisdiction, and infrastructure—all of which must be adequately tiered to ensure long-term feasibility of the mine. It was not just up to miners or geologists to create assets or feasibility. By understanding this basic fact, they realised that reconnaissance and exploration were highly lucrative standalone businesses. When miners do reconnaissance and exploration, mining companies look at it like a cost component.

Exploration Companies: When explorers did business, they looked at it as an independent profit centre. And mind you, this was much more—it was an order of magnitude more profitable than mining. Why were they barred from the most profitable business ever? The speaker shared the list of the top 20 exploration junior companies from 2025. All those values were just from 2025. The small and micro businesses had grown their valuations between 722% to 4800%. These were stock market data; these were all listed companies. The speaker gave a list of seven investors in exploration junior companies. He had had the good fortune of working with two of them. They had made over 100% return in 2025 on their investment.

Why, as a nation, were they systematically barred from participating in this most profitable, discovery-driving segment of this critical industry? Many of these jurisdictions thrived because they had a mature pact: companies declared extreme risk, and informed adults chose to invest.

The rewards funded the next discovery, which fuelled national security. They had seen the global race, the technology, the astronomical returns. Now, they must ask why India was not a player in this game.

Structural Rigidities: To address the exploration chasm that currently threatens India's mineral sovereignty, they must look beyond geology and confront the structural rigidities of their current framework. The bottleneck was right there—at the very first reconnaissance and exploration. Their system was designed with four fundamental locks to the door of discovery.

First was the auction trap: India chases transparency and short-term revenue maximisation, bidding away the future margins they needed to fund sophisticated exploration that actually found the ore.

Second, they had a reconnaissance vacuum: the high-risk early stage was left to the state, while the world's risk capital sat on the sidelines because there were no finder's fees.

Third, India lacks the entire junior mining ecosystem. Where were India's TSX or ASX listed exploration rocket ships? They did not exist.

Fourth, the most critical was the security of tenure disconnect. Imagine a tech startup that invented a breakthrough only to have its IP auctioned to the highest bidder. That was their exploration model. This modelled out innovation. Why invest in innovation, financial tools, AI, and advanced sensors if you cannot capture the full value of the discovery they enabled?

Yet there was a key: the 2025 amendment of Mineral Exchanges—this could be a revolution if they allowed tenements to be traded like assets and let investors share the thousand per cent returns that drove global exploration; they could unlock the door[28].

Conclusion: The conclusion is evident ; we achieve Viksit Bharat and mineral security when we spread these chains. We must build an ecosystem where the finder truly wins. The future we are fighting for is a scenario where there is synthesis - a marriage of our technological genius with our national ambition.

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28. Ministry of Mines, (31 Dec 2025), End of Year Review https://www.pib.gov.in/PressReleasePage.aspx?PRID=2210011&reg=3&lang=2

It includes measures like using homegrown and proven technologies like CAGE-IN to discover deposits with precision, using green technology to process cleanly and manufacturing our own Rare Earths Permanent Magnets.

We must begin to see e-waste as a strategic reserve and view mineral alliances as a force multiplier.

The ultimate goal is not to recreate dirty mines of the past, but to pioneer a clean, smart and sovereign resource ecosystem of the future where growth is powered by intelligence and security is built on innovation. That is the transition needed to pivot from the pickaxe to algorithms and to secure an opportunity to lead.

RECOVERY & RECYCLING CRITICAL MINERALS : SCOPE & WAY FORWARD FOR INDIA (Virtual Session)

Dr. Abhinav Mathur

Dr Mathur opened by noting the topic of challenges and the way forward in critical minerals, linking it to recycling. He introduced Attero as India's largest electrical and electronic waste recycler, operating since 2017 (with technology development starting in 2008, giving 17 years of experience). Attero focuses on establishing right policies, technologies, and ecosystems for sustainable recycling.

He highlighted Attero's unique capabilities: the only recycler globally extracting over 22 elements from the periodic table from various e-waste streams. While Indian government regulations require recyclers to recover only four elements (iron, copper, aluminium, and gold), Attero exceeds this by recovering 22+ metals. The company has a processing capacity of nearly 175,000 tons per annum of e-waste and handles about 20,000 tons of lithium-ion batteries annually—an area experiencing rapid growth. Attero holds over 45 patents (with more in development), serves as the largest Extended Producer Responsibility (EPR) provider, and maintains high compliance in environmental, security, and other regulatory areas. It has received multiple awards in recent years for innovation. The speaker mentioned Attero's inauguration by Dr. A.P.J. Abdul Kalam, who emphasised innovation, a focus that the company has continued. Attero has also been recognised by the Honourable Prime Minister on several occasions.

Acknowledging the prior session's coverage of critical minerals geopolitics, initiatives in mining, and related topics, Mathur skipped repeating those details but stressed that emerging sectors—clean energy technologies (e.g., electric mobility), defence, space, and semiconductors—depend heavily on critical materials. These minerals carry high economic importance and supply chain risks globally, largely due to China's control over midstream processing and end-product manufacturing, despite diverse sourcing countries. China has invested significantly, achieving dominance. India's efforts to build ex-China supply chains include establishing Khanij Bidesh India Limited (KABIL) under the Ministry of Mines to secure overseas mines for battery materials, with discussions involving Australia, Argentina, and Chile (limited progress, some success with Argentina).

NCMM: In August 2024, the Ministry of Mines launched the National Critical Minerals Mission (NCMM) to promote self-reliance amid China's export restrictions and border tensions. Recent talks aim to position India as a global hub for critical minerals in academia, technology, and supply. The NCMM rests on seven pillars: increasing domestic production, acquiring overseas assets via KABIL, developing trading markets, funding scientific research and technological advancement, capacity building, effective financing/fiscal incentives, and recycling of critical minerals (a highly important pillar).

The mission entails ~ ₹34,300 crore overall; the first Cabinet-approved incentive was ₹1,500 crore specifically for promoting critical minerals recycling, driven from the top. Announcements are expected soon for India as a global recycling hub, underscoring recycling's strategic significance [30].

Growing e-waste crisis: India ranks third globally in e-waste generation (~3.2 million tons out of 44 million tons unmanaged worldwide). Improper recycling leads to massive resource loss—~60 elements from the periodic table are in e-waste and lithium-ion batteries. Without efficient methods, global losses reach $57 billion; India's alone ~$2.24 billion (projected to rise to $10.61 billion without investment). Failure means increased imports, heightening risks to manufacturing ecosystems.

Challenges stem from a dominant informal recycling sector focusing only on base metals (copper, aluminium, iron) using primitive, harmful methods (burning, acid leaching), discarding remnants into water/land, causing environmental and health damage. Precious metals (gold, silver, platinum group), critical minerals (lithium, cobalt, nickel, manganese), and rare earths

29. National Critical Minerals Mission, (2025), https://mines.gov.in/webportal/content/national-critical-mineral-mission
30. Ministry of Mines, (29 Jan 2025), Cabinet Approves 'National Critical Mineral Mission' to build a resilient Value Chain for critical mineral resources vital to Green Technologies, with an outlay of Rs.34,300 crore over seven years, https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=2097309&reg=3&lang=2

(neodymium, praseodymium—recently restricted by China) remain unextracted.

EPR Norms: The government introduced Extended Producer Responsibility (EPR) norms, wherein producers benefiting economically from sales must ensure end-of-life recycling, recovering materials in pure form for reuse. Simplified analogy, Coca-Cola must handle plastic bottle recycling, not just governments/municipalities. Extended to batteries and e-waste, e.g., if LG sold 1 lakh tons of ACs in 2010, it must recycle ~70,000 tons in 2020 (illustrative). EPR drives formal setups, increases waste to recyclers, extracts materials, and supplies manufacturers[31] —reducing dependence on China.

China taps informal global ecosystems to source and recycle end-of-life products domestically, perpetuating reliance; domestic recycling counters this. CPCB and DGFT rules now prohibit exports of end-of-life lithium-ion batteries or e-waste containing precious/critical/rare earth materials. Example calculation: High-efficiency formal recycling of 2 lakh tons of e-waste yields ~10,000 tons of copper, 2,000 tons each of nickel/cobalt/tin/indium/rare earths—natural resources for domestic use.

Global Initiatives: Global initiatives include the US Inflation Reduction Act, Canada's Critical Minerals Strategy, EU Critical Raw Materials Act, China's export restrictions, and partnerships, e.g. Mineral Security Partnership with Japan, USA, Australia, and India for supply visibility.

31. E-Waste Management System, (2022), https://eprewaste.cpcb.gov.in/

India must leverage these to become a recycling/critical minerals recovery hub, as its technology rivals China's and the world seeks ex-China chains[32, 33, 34, 35]

Challenges: Current recycling is structured as environmental compliance (EPR focuses on avoiding landfills), not strategic mineral recovery. Regimes do not differentiate recycler quality: coverage of materials (e.g., 5 vs. 22 elements), extraction efficiency (e.g., 5g vs. 10g gold from a laptop), purity (for high-value vs. low-grade uses), environmental impact, and domestic retention. Better recyclers need priority access/support. Weak enforcement allows "paper recycling" without actual processing (reported instances); this must stop.

To accelerate sustainability, circularity, and self-reliance in Critical Minerals, he recommended:

1. Recognise recycling as strategic mineral infrastructure — Update e-waste rules to list 30 critical minerals (not just four), incentivise full extraction. Treat CRM-bearing e-waste/batteries as urban mines; ban exports. Integrate as a secondary supply pillar alongside mining (align with EU-style rules mandating recycled content in new products).

32. Inflation Reduction Act (2022), https://www.irs.gov/inflation-reduction-act-of-2022
33. The Canadian Critical Minerals Strategy https://www.canada.ca/en/campaign/critical-minerals-in-canada/canadian-critical-minerals-strategy.html
34. European Commission, (16 March 2023), European Critical Raw Materials Act https://commission.europa.eu/topics/competitiveness/green-deal-industrial-plan/european-critical-raw-materials-act_en
35. MEA, (02 July 2025), Factsheet : 2025 Quad Foreign Ministers' Meeting in Washington D.C. (July 01, 2025), https://www.mea.gov.in/bilateral-documents.htm?dtl/39734/Factsheet++2025+Quad+Foreign+Ministers+Meeting+in+Washington+DC+July+01+2025

Align policies with import substitution, energy transition, defence, and manufacturing goals.

2. Institutional convergence and urban mine governance — Coordinate ministries; direct critical minerals-bearing waste to capable recyclers. Auctions (MSTC/GEM) must prioritise strategic recovery objectives. Educate households/MSMEs/ government on returning obsolete devices (laptops, PCs, smartphones). Create a national recycler repository, rating system for capability-based flows.

3. Economic viability, enforcement, formalisation — Raise low EPR pricing (ongoing high court case; needs minimum fees for scientific profitability/investment attraction). Rationalise GST (reduce, reverse charge, liquidity support) to level informal sector advantages (no taxes/safety/environmental norms). Mandate recycled content in products; support stockpiling of recycled materials (parallel to KABIL). Ensure digital traceability/accountability for materials in households/MSMEs/government; track contributions to manufacturing. Think tanks (e.g., NITI Aayog) estimate 40–50% of national needs by 2035–2040 will be met via proper recycling, avoiding imports.

Mathur concluded by summarizing these points for better circularity.

CHINA'S LEVERAGE & GLOBAL RARE EARTHS TRADE (Virtual Session)

Dr. Nabeel Mancheri

Dr Mancheri began by thanking the Indian Council of World Affairs (ICWA) and the Asia Centre, Bangalore, for organising the event, and expressed his gratitude to Lt. Gen. C.A. Krishnan and Rishi Athreya for the invitation. He outlined that his presentation would focus on China's leverage in global trade, particularly in critical raw materials, and the steps India must take to overcome emerging strategic bottlenecks.

He explained that he works with the European Institute of Innovation and Technology (EIT), an agency of the European Commission that supports academic research, start-ups, mining, recycling, processing, and substitution projects across Europe. The organisation functions partly on the lines of India's CSIR, funding innovation while also facilitating networks across the EU, including the Balkans.

China's dominance in critical raw materials: Dr Mancheri highlighted that China dominates almost the entire spectrum of critical raw materials, including copper, nickel, cobalt, lithium, and rare earth elements. Over the last 15 years, China has increasingly used its control over these materials as a geo-strategic weapon. As a result, countries such as the United States, Japan, Canada, and members of the European Union have been attempting to diversify their supply chains away from China.

He noted that while diversification has occurred at the mining stage, it has largely failed at the processing and value-addition stages. Even when mining takes place in Africa, Australia, the United States, or Southeast Asia, most ores are still sent to China for processing. As a consequence, China controls roughly 65% of rare earth mining but over 85% of processing capacity.

The rare earth value chain and strategic applications: Dr Mancheri explained that the most critical application of rare earths today lies in permanent magnets. These magnets are essential for electric vehicles, wind turbines, consumer electronics, drones, industrial robots, and modern defence systems. High-performance permanent magnets rely primarily on neodymium and praseodymium, with small quantities of heavy rare earths such as dysprosium and terbium for higher strength.

Despite limited diversification in mining, China has retained near-total control over metallisation and magnet manufacturing. Over the past five decades, diversification in mining has paradoxically helped China secure more raw materials from the rest of the world while consolidating its dominance in processing and finished products.

Myanmar and Africa, strategic sourcing by China: Dr Mancheri discussed Myanmar as a critical case study. Nearly 40% of China's neodymium requirements are sourced from Myanmar. China supports mining operations on both sides of Myanmar’s internal conflict, including areas controlled by the military junta and the Kachin Independence Army (KIA), thereby safeguarding its strategic interests. Similar patterns are observed across Africa, where monazite and other rare earth-bearing minerals are extracted and sent to China for processing.

Countries such as Nigeria, Madagascar, Laos, Thailand, Vietnam, and Malaysia contribute raw materials to China, either legally or illegally. Even where processing occurs outside China—such as in Australia or Malaysia—significant portions of the processed output ultimately feed Chinese value chains.

Export restrictions and geopolitical leverage: Dr. Mancheri explained that China has increasingly shifted from exporting rare earth oxides to exporting finished products, particularly permanent magnets. In 2024, nearly half of China’s permanent magnet exports were destined for the European Union, followed by the United States, Japan, South Korea, and India.

China Export Restrictions: In 2025, China introduced export restrictions under international trade law, selectively targeting countries based on geopolitical considerations. India’s automotive sector was severely affected, with companies such as Tata Motors and Mahindra facing supply disruptions. Japanese firms operating in India also encountered licensing delays and regulatory hurdles.

He emphasised that although global demand for permanent magnets typically grows by 10–15% annually, export controls caused volatility and uncertainty. Even when quantities remained similar to previous years, the threat of sudden disruption demonstrated how raw materials could be weaponised strategically.

India's dependence and strategic vulnerability: Dr Mancheri pointed out that India imports approximately 2,500 tonnes of permanent magnets annually from China and does not currently produce even a single kilogram domestically. While Indian Rare Earths Limited (IREL) can process certain upstream materials, metallisation and commercial-scale magnet production remain absent.

He welcomed the Indian government's announcement of USD 750–800 million to support permanent magnet manufacturing, noting that this investment is crucial not only for strategic autonomy but also for positioning India as an alternative supplier to global markets. Countries in Europe and North America increasingly view India as a potential second source for critical materials.

Global responses: lessons from the EU and the US: Dr Mancheri described the European Union's Critical Raw Materials Act, which mandates that by 2030[36]:

- At least 10% of mining must occur within the EU.
- 25% of materials must be recycled domestically.
- 40% of processing must take place within the EU.
- No more than 65% of any critical material may be sourced from a single country.

The EU has also introduced laws restricting the export of end-of-life products, including permanent magnets and battery black mass, to prevent strategic leakage back to China.

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36. European Commission, (16 March 2023), European Critical Raw Materials Act https://commission.europa.eu/topics/competitiveness/green-deal-industrial-plan/european-critical-raw-materials-act_en

In the United States, he noted a major shift toward state intervention. The US Department of Defense has committed nearly USD 1 billion to MP [Mountain Pass] Materials to establish a mine-to-magnet supply chain. Several South Korean and European firms are also setting up magnet and processing facilities in the US, driven by substantial subsidies and policy incentives [37, 38]

The way forward for India: Dr Mancheri stressed that India must build an integrated value chain encompassing mining, processing, metallisation, and magnet manufacturing. Competing with China requires state-backed intervention, as private firms alone cannot compete with the Chinese state's scale and subsidies.

He emphasised the importance of public–private partnerships, downstream procurement commitments, and policies restricting the export of end-of-life rare earth products. Recycling must be integrated into the primary value chain to ensure material security. According to Dr Mancheri, with the right policy support, India can secure its own strategic autonomy while also supporting allied countries and offering African nations alternatives to China's resource dependency.

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37. Department of War, (11 March 2024), DOD Looks to Establish 'Mine-to-Magnet' Supply Chain for Rare Earth Materials, https://www.war.gov/News/News-Stories/Article/Article/3700059/dod-looks-to-establish-mine-to-magnet-supply-chain-for-rare-earth-materials/
38. MP Materials, (10 July 2025), MP Materials Announces Transformational Public-Private Partnership with the Department of Defense to Accelerate U.S. Rare Earth Magnet Independence, https://mpmaterials.com/news/mp-materials-announces-transformational-public-private-partnership-with-the-department-of-defense-to-accelerate-u-s-rare-earth-magnet-independence/

Dr Mancheri concluded by reiterating that critical raw materials are no longer mere commodities but instruments of strategic power. Diversifying away from China requires coordinated state action, long-term industrial planning, and alignment across the value chain. He thanked the Asia Centre and ICWA once again for the opportunity to share his insights.

IREL IN INDIA'S CRITICAL MINERAL ROADMAP

Dr. P. Krishnamurthy

Dr Krishnamurthy began by expressing his appreciation for being part of what he described as a highly enlightening endeavour. He referred to a meeting held in October 2025 at the Capitol Hotel titled Innovations Rarer Than Lithium (IRLI 25), organised by the Critical Minerals Association of India, and described the present discussion as a natural extension of that initiative[39, 40]

He clarified that while much has already been said about India's dependence on imported rare earth materials, particularly the inability to produce neodymium–iron–boron (NdFeB) magnets domestically, the deeper issue lies even further upstream, at the level of intermediate compounds and materials. He noted that his long-standing association with the Atomic Minerals Directorate (AMD), spanning over three decades, and his current role with the Geological Society of India have shaped his perspective, particularly in relation to the dissemination of earth science knowledge.

39. Innovation in REE & Lithium 09 -10 October 2025, https://criticalminerals-events.com/irli/
40. https://criticalmineralsassociation.in/

Historical foundations of India's atomic and rare earth programme: Dr Krishnamurthy traced India's rare earth journey to the vision of Dr Homi Jehangir Bhabha. After completing his PhD at Cambridge, Dr Bhabha returned to India in 1942 and, with support from the Tata group, founded the Tata Institute of Fundamental Research (TIFR). Following independence, and in close collaboration with Prime Minister Jawaharlal Nehru, Dr Bhabha established India[41] 's atomic energy programme, culminating in the Atomic Energy Act of 1948. A central question posed by Dr Bhabha was the availability of indigenous raw materials, uranium, thorium, and rare earths. This led to the creation of dedicated institutional mechanisms to explore and secure these resources. Uranium was successfully discovered at Jaduguda in 1949–50, marking one of India's earliest successes in atomic mineral exploration.

India's beach placer deposits, rich in monazite containing thorium and rare earths, became the cornerstone of the country's long-term nuclear strategy. Given the high thorium content of Indian monazites, Dr Bhabha conceptualised India's three-stage nuclear programme, with the third stage relying on uranium-233 bred from thorium, offering a potentially near-limitless energy source.

Evolution of exploration institutions: Dr Krishnamurthy highlighted the role of Dr D. N. Wadia, the Geological Advisor to the Government of India, as a foundational figure in India's mineral exploration efforts.

41. https://www.tifr.res.in/portal/history.php

During the Second World War, the British administration sought rare metals such as beryllium and niobium, prompting the Geological Survey of India to establish a dedicated Rare Minerals Survey Unit around 1942[42]–43. Following independence and the Atomic Energy Act, this unit was absorbed into the atomic energy framework and eventually evolved into the Atomic Minerals Directorate for Exploration and Research (AMD). Dr Wadia played a decisive role in shaping AMD's exploration philosophy, making him, in Dr Krishnamurthy's words, the true father of India's atomic mineral exploration programme.

India's current rare earth challenge: Dr Krishnamurthy emphasised that the strategic importance of critical minerals has now been fully recognised by the Government of India, particularly in the context of the national goal of achieving developed-nation status by 2047. He stressed that this recognition must translate into concrete action rather than remain at the level of policy intent.

He cited the situation in the financial year 2024–25, during which India imported over 53,000 metric tonnes of rare earth magnets. This is despite possessing approximately 8% of the world's rare earth reserves, largely concentrated in monazite sands across Andhra Pradesh, Odisha, Tamil Nadu, and Kerala. Yet, India accounts for less than 1% of global rare earth production[43].

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42. https://www.wihg.res.in/founder
43. Rare Earths Armistice: India's Shift from Mining to Processing, https://www.orfonline.org/expert-speak/rare-earths-armistice-india-s-shift-from-mining-to-processing

The National Critical Minerals Mission: To address this gap, Dr Krishnamurthy referred to the launch of the National Critical Minerals Mission in January, with an outlay of ₹16,300 crore under a broader allocation of ₹34,300 crore spread over seven years. The mission focuses on exploration, processing, and recycling of critical minerals such as lithium, cobalt, and rare earths, including recovery from waste streams[44] .

He noted that detailed assessments of this mission and the role of Indian Rare Earths Limited (IREL) would be published in the February issue of the Geological Society of India's journal, highlighting encouraging progress through combined public and private participation.

Rare earth elements and their geological context: Dr Krishnamurthy confined his technical discussion to rare earth elements — lanthanum through lutetium, along with yttrium and scandium. Referring to an unconventional periodic table prepared by European scientific bodies, he explained that while many elements are abundant in the Earth's crust, the real challenge lies in their concentration, location, and economic extractability. He observed that although rare earths are distributed throughout the crust, identifying viable deposits and extracting them efficiently remains a complex geological and technological challenge. Monazite, in particular, has played a historic role in India's rare earth narrative.

Monazite and India's long mining history: Dr Krishnamurthy recounted that monazite from Indian sources was first identified by German scientists in 1909, when sand

44. National Critical Minerals Mission, (2025), https://mines.gov.in/webportal/content/national-critical-mineral-mission

grains found in ship ropes drew their curiosity. At the time, thorium extracted from monazite was used for incandescent gas mantles such as the Petromax lamp. This led to early German mining activity in India, including the establishment of plants at Manavalakurichi and Chavara. Following independence, Indian Rare Earths Limited (IREL) was formally established in 1950, though private participation continued until 1963, after which operations came fully under the Department of Atomic Energy. Export of monazite was subsequently prohibited, reflecting its strategic importance[45] .

Resource assessment and mineral beneficiation: Dr Krishnamurthy explained that identifying mineral availability requires systematic exploration, quantification, and beneficiation. AMD has been engaged in this task since 1949. By 2024, India's assessed beach sand mineral resources included approximately 726 billion tonnes of ilmenite, one of the world's largest concentrations of titanium-bearing minerals. Other significant minerals include sillimanite, garnet (a source of yttrium), zircon, rutile, and monazite. He pointed out that India exported garnet extensively for decades, particularly to Japan, and noted that the extraction of yttrium from these garnets remains an unresolved mystery. India's monazite reserves are estimated at around 13.15 billion tonnes, accounting for roughly 6% of global rare earth resources, largely concentrated along the eastern and western coastal belts. These deposits form through weathering, transport, and wave action, but proving them requires extensive sampling due to low monazite concentrations in beach sands[46] .

45. https://www.irel.co.in/quick-aboutus
46. Department of Atomic Energy, (23 July 2025), Parliament Question: Rare Earth Minerals, https://www.pib.gov.in/PressReleasePage.aspx? PRID = 2147282 & reg=3&lang=2

Processing infrastructure and technological progress: Dr Krishnamurthy outlined the multi-stage process undertaken by IREL, involving mining of beach sands, physical separation using magnetic and gravity techniques, and recovery of individual mineral fractions. He referred to operational plants at locations such as OSCOM (Odisha Sands Complex), Chavara (Kerala), Manavalakurichi (Tamil Nadu), and Chhatrapur. Chemical separation of rare earth oxides is carried out at IREL's Rare Earths Division in Aluva, Kerala, where further research is conducted in collaboration with universities and research institutions. He highlighted the establishment of a new facility at Bhopal, designed to advance rare earth metal production, magnet development, and recycling of end-of-life products under the Critical Minerals Mission.

Defence preparedness and outlook: Dr Krishnamurthy noted that the Defence Metallurgical Research Laboratory (DMRL) has successfully demonstrated rare earth metal production at the laboratory scale. According to senior DMRL scientists, India's strategic sectors, such as atomic energy, defence, and space, are not currently vulnerable. However, large-scale commercial demand, particularly for electric vehicles and consumer applications, remains unmet.

He concluded by stressing the need for national participation in the Critical Minerals Mission, urging adaptability and innovation. Quoting Charles Darwin, he remarked that survival depends not on strength or intelligence alone, but on adaptability to change. On this note, he reaffirmed his commitment to contributing to Bharat's rare earth and critical minerals mission and thanked the organisers for the opportunity.

CRITICAL MINERALS : INITIATIVES BY GOVT OF INDIA

Dr R. Saravanabhavan

Dr Saravanabhavan began by acknowledging the senior geologists, colleagues, and participants present at the session. He expressed personal satisfaction at speaking in Bengaluru, noting that he had started his professional career in the city, and thanked the Asia Centre Bangalore for the invitation. He also extended New Year greetings to the audience before proceeding directly to the subject of critical minerals.

Understanding critical minerals and criticality: Dr. Saravanabhavan clarified at the outset that critical minerals should not be discussed in a fragmented manner. Rare earths are an integral part of the critical minerals framework, as rare earth elements are included among the 24 critical minerals officially identified by the Government of India.

He explained that the concept of criticality is defined by the convergence of two factors: high economic importance and high supply risk. To illustrate this, he cited India's experience with copper. Until May 2018, India was largely self-sufficient in copper. However, the closure of the Sterlite Copper plant following political unrest resulted in a sharp decline in domestic production from approximately 8.8 lakh tonnes to about 4.2

lakh tonnes, instantly creating a supply deficit of around 4.6 lakh tonnes. This, he noted, exemplifies how supply disruptions transform an economically important mineral into a critical one.

Climate change, emissions, and the role of critical minerals: Dr Saravanabhavan highlighted why critical minerals have gained prominence in recent years. Sector-wise analysis shows that around 38% of critical minerals are required by the power sector and about 17% by industrial combustion. Together, these sectors account for nearly 55% of global CO_2 emissions, making them central to climate mitigation efforts. He referred to temperature data showing that during the first hundred years leading up to 2007, global temperatures rose by approximately 0.8–0.9°C. In contrast, over the subsequent 15–20 years, temperature increases accelerated dramatically, reflecting a multiple-fold increase in the rate of warming. India's share of global emissions stands at about 6.52%, placing it among the major contributors, which explains the government's seriousness in addressing climate-linked mineral security.

Dimensions and global identification of critical minerals: Dr Saravanabhavan explained that criticality is assessed across five dimensions: economic, supply chain, technological, geopolitical, and geological. Different countries, therefore, identify different sets of critical minerals based on national priorities.

He outlined comparative figures of various countries, the United States identified 50 critical minerals in 2022 and has since expanded the list; the European Union has 34; Japan has 35, and Canada has 31; Australia has 30; China is believed to have 24 and India, after an initial identification of 30 minerals, has narrowed its list to 24 critical minerals through the NCMM framework [47, 48, 49, 50, 51, 52]

China's dominance and India's exploration gap: Using global mining and processing data, Dr. Saravanabhavan demonstrated China's dominance across nearly all major critical minerals. China holds leading shares in cobalt, copper, lithium, nickel processing, and rare earths. Even where minerals are mined outside China, a significant proportion is sent back to China for processing and manufacturing.

Decline in India: He noted that in 2013, India ranked third globally in terms of rare earth resources, but by 2022 had fallen out of the rankings, reflecting declining exploration intensity. India currently spends less than 1% of global exploration budgets, which he identified as a major structural weakness. He observed that India's historical focus has been on bulk minerals such as iron ore, limestone, and bauxite, while deep-seated and strategic minerals were largely neglected. As a result, potential by-products such as scandium associated with bauxite were

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47. USA Critical Mineral List, (2025), https://www.federalregister.gov/documents/2025/11/07/2025-19813/final-2025-list-of-critical-minerals
48. Fifth list 2023 of critical raw materials for the EU, (16 March 2023), Annex II of the Regulation proposal COM(2023), https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en
49. Nogimor, M, (Jan 2024)Restructuring of Critical Mineral Supply Chain Faces "Trilemma, JRI Research Journal, https://www.jri.co.jp/en/MediaLibrary/file/english/periodical/jrirj/2024/01/nogimori.pdf
50. Canada Critical Minerals, https://www.canada.ca/en/campaign/critical-minerals-in-canada/critical-minerals-an-opportunity-for-canada.html
51. Australia's Critical Minerals List and Strategic Materials List, https://www.industry.gov.au/publications/australias-critical-minerals-list-and-strategic-materials-list
52. NCMM, Ibid

ignored. He contrasted this with China's long-term strategic planning, which enabled it to capture value from such overlooked resources.

Lead times and structural challenges in India: Dr Saravanabhavan explained that globally, the average lead time from mineral discovery to production is approximately 15.5 years. In countries such as Turkey, Chile, the Democratic Republic of Congo, Burkina Faso, Australia, and China, this process typically takes between 11 and 14 years. In India, however, social opposition and regulatory delays can permanently stall projects, significantly increasing uncertainty. India faces two main challenges, namely, low levels of exploration investment and a lack of advanced technology for deep-seated and critical mineral exploration.

India's global partnerships: Dr Saravanabhavan traced India's international engagement on critical minerals to the Prime Minister's visit to the United States in June 2023, when India joined the Minerals Security Partnership. India is fully import-dependent for 15 critical minerals and partially dependent for others. A small group of countries controls a majority share of minerals such as cobalt, copper, graphite, lithium, manganese, nickel, and rare earths, reinforcing India's vulnerability. At present, India has substantial domestic resources only in the case of rare earths; for most other critical minerals, domestic availability remains limited.

National Critical Minerals Mission: Dr Saravanabhavan then turned to the National Critical Minerals Mission (NCMM), with which he has been closely involved. The mission covers all 24 identified critical minerals, spans seven years, and has a total outlay of ₹16,300 crore. Its components include exploration, beneficiation, processing, recycling, and international collaboration[53] .

Recycling and secondary resources initiatives: He described the recycling incentive scheme launched on 3 September, with an outlay of ₹1,500 crore over six years. The scheme supports the separation and production of critical minerals from secondary sources, including e-waste, lithium-ion battery scrap, catalytic converters, and end-of-life vehicles. Eligible beneficiaries include large, small, and new recyclers. Incentives include 20% CAPEX and OPEX subsidies linked to incremental sales, with defined caps for large and small entities. The target outcome is an annual recycling capacity of 270 kilo tonnes, yielding approximately 40 kilo tonnes of critical minerals.

Production-linked incentives and raw material constraints: Dr. Saravanabhavan outlined the Rare Earth Permanent Magnet (REPM) production-linked incentive scheme, developed in coordination with the Department of Heavy Industries and endorsed in April 2025. The scheme has a total outlay of ₹7,280 crore, including capital subsidies, and aims to allocate production capacity to five beneficiaries through competitive bidding. A key constraint, he noted, is raw material availability. IREL's current capacity for rare earth oxides is limited relative to projected magnet production requirements, creating a gap that must be addressed through capacity expansion, overseas sourcing, or recycling support.

Mineral block allocation and research initiatives: Dr Saravanabhavan noted that critical mineral blocks have been

53. NCMM, Ibid

allocated through the composite licence route across several states, including Rajasthan, Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Uttar Pradesh, Bihar, Arunachal Pradesh, Jharkhand, Odisha, and Chhattisgarh.

Centres of Excellence: He also highlighted the establishment of nine Centres of Excellence under the NCMM, involving institutions such as IIT Bombay, IIT Hyderabad, IIT ISM Dhanbad, IIT Roorkee, NML, CMET Hyderabad, and others. These centres operate through collaborative partnerships and are supported by the Maha CRM research programme under the National Research Foundation framework[54].

New Initiatives: Added initiatives include exploration of secondary resources such as mine tailings, coal mine residues, fly ash, and red mud from bauxite processing. While fly ash utilisation faces implementation challenges, significant progress has been made on red mud, with flow sheets developed and pilot work underway.

Institutional coordination and way forward: Dr Saravanabhavan concluded by outlining the coordinated roles of various ministries. The Ministry of Mines is driving sectoral reforms and policy framework, and the Ministry of Coal and public sector enterprises are exploring overseas asset acquisition.

The Ministry of External Affairs is facilitating strategic partnerships; the Department of Science and Technology is supporting research funding; CSIR laboratories are accelerating extraction and processing technologies; and the Department of

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54. National Critical Minerals Mission, (2025), https://mines.gov.in/webportal/content/national-critical-mineral-mission

Atomic Energy continues to act as custodian and stockpiler of rare earth materials.

He thanked the organisers for the opportunity to share these perspectives and reaffirmed the government's commitment to strengthening India's critical minerals ecosystem.

PIONEERING LITHIUM RECYCLING IN INDIA

Mr Manish Rathi

Mr Manish Rathi represents Mini Mines Clean Tech Solutions, the only R4 recycler in Southern India. The company specialises in the extraction of five critical minerals from end-of-life lithium-ion batteries and battery waste through a proprietary hydro-metallurgical process developed indigenously. Mr. Rathi holds a Master's degree in Chemical Engineering from IIT Bombay and has over ten years of experience in clean air and emissions control. He has been involved in business operations across multiple mines, including a 3,000 MTPA operation for the procurement of waste batteries and the sale of recovered materials such as lithium carbonate, nickel sulphate, cobalt sulphate, copper, and graphite. As part of a circular economy vision, Mini Mines has recently signed a ₹350 crore MoU with the Government of Karnataka for the establishment of 15,000 MTPA material recovery units from spent batteries, cell giga-factory scrap, and other secondary materials within the state.

Mr. Rathi began by introducing himself as being based in Bengaluru and representing Mini Mines Clean Tech Solutions. He noted that the company operates facilities located approximately an hour's drive from the venue at Doddabalapur, along with another unit at Gauribidanur near the Karnataka–Andhra Pradesh border[55]. He stated that Mini Mines focuses on the recovery of critical minerals, specifically five minerals identified under the Union Government's critical minerals list, and that the company is currently scaling its operations commercially to ensure that recycled materials are made available domestically profitably and sustainably.

Urban mining and the role of secondary resources: Referring to earlier discussions on the long timelines associated with primary mining, Mr Rathi highlighted that while conventional mining can take up to 15 years to bring a mineral into production, secondary resources offer a much faster alternative. Urban mining, he explained, enables recovery of the same critical materials within weeks by sourcing them from end-of-life products and reintegrating them into the formal industrial value chain.

He emphasised that Mini Mines' core focus lies in urban mining through the recovery of metals from spent lithium-ion batteries. The company provides battery disposal services primarily to electric vehicle manufacturers and electronics producers, and also works closely with lithium-ion cell giga factories that are emerging across South India.

Engagement with manufacturers and EPR compliance: Mr Rathi noted that several cell giga factories are coming up in South India, led by companies such as Ola Technologies, Exide Energy, and Amara Raja.

55. Mini Mines, https://m-mines.com/

He explained that extended producer responsibility (EPR) has become central to formalising recycling practices, ensuring environmentally sound processing while helping producers meet compliance targets mandated by pollution control boards and government authorities. Recovered materials are supplied back into industry, both within domestic markets and through participation in global value chains. He added that Mini Mines' work has been recognised by organisations including Oil India, the United Nations Industrial Development Organisation, CII, Cummins, and Benz.

Electric vehicle growth and material demand: Mr Rathi drew attention to the exponential growth of the electric vehicle market in India. While early adoption focused on two- and three-wheelers, electrification is now expanding into trucks and tractor segments that were previously considered unlikely to transition. He explained the material composition of lithium-ion batteries, particularly those used in two-wheelers, which dominate India's automotive fleet. Such batteries typically contain approximately 7% lithium, 22% nickel, along with manganese, copper, aluminium, graphite, and cobalt. All these materials are essential inputs for battery manufacturing. He observed that the rapid expansion of electric mobility makes a transition from a linear economy to a circular economy imperative if India is to achieve self-reliance in critical minerals.

Import dependence and end-of-life challenges: Mr Rathi pointed out that India currently lacks substantial domestic reserves for most battery minerals, apart from recently discovered lithium resources. Even where decisions are taken today to develop primary resources, it would take several decades to bring lithium into production. In the interim, import dependence remains significant, with growing foreign exchange outflows to meet rising material demand. He also highlighted the challenge of managing batteries at the end of their life cycle, noting the need for structured systems to address disposal after five, ten, or fifteen years of use.

Second-life applications of batteries: Mr Rathi explained that battery end-of-life is determined by health metrics. In consumer electronics, batteries are typically replaced once health drops to around 60%, while in electric vehicles, the cutoff is closer to 80% due to safety considerations. Batteries above this threshold still retain usable life. At Mini Mines, batteries are tested to determine whether they can be repurposed for second-life applications. These include hybrid solar and grid-based energy storage systems, where batteries function as energy units rather than high-power discharge units. Such applications often replace lead-acid batteries and extend overall battery utilisation before recycling, thereby generating additional economic value and reducing import dependence.

Recycling process and material recovery: Once batteries are declared end-of-life, they are sent for recycling. Mr Rathi explained that lithium-ion batteries are hazardous in nature and must be handled carefully, in compliance with UN 38.3 safety standards. At the facility, batteries are safely discharged and dismantled before undergoing a controlled hydrometallurgical process. Metals are recovered in a staged manner, beginning with graphite, followed by nickel, cobalt, and manganese, and finally lithium, which is extracted at the last stage. Mr Rathi emphasised that the process developed over the past four years is capable of handling all battery types and formats, ranging from small coin cells to large-format cells weighing up to four kilograms used in energy storage systems.

Recovery efficiency, sustainability, and indigenisation: Mr Rathi stated that Mini Mines achieves approximately 96% recovery by weight, with purity levels exceeding 99%, meeting both industrial-grade and battery-grade specifications. This level of recovery is essential for making recycling economically viable and aligns with requirements under government PLI schemes. He highlighted that the entire recycling ecosystem—from process design to machinery, reactors, and extraction units—has been developed indigenously, ensuring that no equipment needs to be imported. This approach supports domestic manufacturing and positions India to export recycling technologies globally in the future.

Environmental impact and process validation: Mr Rathi noted the significant environmental benefits of urban mining. Recovering one tonne of lithium carbonate through recycling saves approximately two lakh litres of water compared to conventional mining. The process involves zero liquid and solid discharge and consumes roughly three-fourths less energy than traditional extraction methods, as it is solvent-based and does not involve heat treatment. He traced the development of the process from laboratory-scale validation in 2021, which was conducted with academic partners, including Rajasthan University, Jaipur. This was followed by a commercial order involving half a metric tonne of recycled material supplied internationally. Subsequently, Mini Mines established a pilot commercial unit, becoming the first entity in Southern India to recover lithium, nickel, and cobalt at scale.

Expansion plans and future outlook: Mr Rathi stated that the company plans to produce a combined 1,200 metric tonnes of lithium, nickel, and cobalt in the next financial year to support domestic battery manufacturing and partner industries. He added that the process has been designed to accommodate not only spent batteries but also mineral ores procured from overseas, allowing flexibility in raw material sourcing. He concluded by noting that Mini Mines has worked closely with the Government of Karnataka on plans to establish 15,000 MTPA recycling and recovery units for secondary materials by 2030. These initiatives aim to strengthen India's critical mineral supply chain through circular economy principles and long-term institutional support.

QUESTION & ANSWER SESSION

Following the insightful presentations and deliberations, the programme transitioned into a panel discussion moderated by Lt Gen CA Krishnan, Director, Asia Centre. The panel brought together experts from academia, industry, policy, and technology to reflect on India's approach to critical minerals, exploration, and downstream capabilities. The session witnessed active participation, particularly from university students, scholars, researchers, and professionals from the mineral industry, who engaged deeply with the issues raised during the deliberations. The questions reflected both conceptual and operational concerns, spanning exploration policy, technological capability, mineral processing, recycling, reporting standards, and commercial viability. A detailed summary of the proceedings is encapsulated in the succeeding paragraphs.

Key Step: Setting the tone for the discussion, the Moderator posed a focused question to the panellists: What is one key step that India must take to strengthen its position in the Critical Minerals ecosystem? One of the key interventions highlighted the importance of off take guarantees coupled with price-risk mitigation mechanisms drawing from international practices. It was argued that long-term off take assurances are critical to enabling private investment, particularly in sectors vulnerable to global price fluctuations. Such mechanisms would ensure stability even in the face of price undercutting by dominant global suppliers. In addition, the need for upfront capital support, rather than solely performance-linked incentives, was emphasised, especially in sectors such as critical minerals and semiconductors, where gestation periods are long and returns are delayed.

Lithium: A prominent line of questioning focused on lithium, widely recognised as a cornerstone of the global energy transition. Participants highlighted the growing mismatch between India's projected lithium demand and negligible domestic capabilities, seeking clarity on prospects for domestic production. While acknowledging the strategic importance of lithium, it was noted that no definitive timeline could yet be offered for domestic production while also addressing the technical, infrastructural, and policy challenges associated with domestic lithium findings, extraction and processing. Measures to acquire resources abroad and securing secure supply chains by establishing alliances were also explained.

Mineral Reporting Standards: Concerns were raised regarding the continued reliance on the United Nations Framework Classification system, which participants argued has contributed to over-optimistic resource assessments and subsequent surrender of mining leases. The discussion highlighted the need for the adoption of internationally accepted, CRIRSCO-compliant reporting codes that are better aligned with commercial mining and exploration practices. It was clarified that the existing classification framework is primarily designed for categorising proven deposits and does not function as an effective reporting mechanism for exploration or economic viability assessments.

Mineral Value Chains: Several participants questioned whether sufficient emphasis was being placed on technological development across the mineral value chain, beyond efforts to diversify supply sources. In response, it was clarified that technological innovations are actively progressing on multiple fronts. Significant advances have been made in reconnaissance and exploration through the use of sensor-based technologies, advanced data interpretation systems, and the integration of public-domain and proprietary datasets. These innovations have demonstrably accelerated exploration timelines while reducing costs and environmental footprints, with measurable gains in efficiency.

Liberalise Exploration: Another theme that emerged was the urgent need to facilitate and liberalise mineral exploration. The panel critiqued the prevailing approach of "firefighting" through short-term fixes in policies, arguing instead for structural reform. India was described as possessing substantial geological potential, with vast tracts available for mineral discovery, including for critical minerals. The primary constraint identified was not a lack of resource availability, but a lack of exploration and exploitation due to a lack of facilitating regulatory and legal frameworks. The call was for the State to step back from excessive control, allowing capable domestic players, who already provide exploration technologies to global markets, to operate freely within India. It was also noted that India's spending on mineral exploration remains disproportionately low compared to global standards, further limiting discovery potential.

Rare Earth Minerals: The discussion also turned to rare earth minerals, particularly those associated with monazite and beach sand minerals. The panel observed that this sector remains largely restricted to public enterprises, despite having been open to private participation in the past. Regulatory shutdowns caused by reported irregularities were acknowledged while also arguing that a complete closure of private participation has created strategic vulnerabilities. With rare earth supply chains increasingly becoming geopolitically sensitive, the panel stressed that self-reliance requires access to domestic ores and monazite resources and a carefully regulated opening of the sector to private players. Without adequate raw material supply, downstream initiatives such as magnet manufacturing and advanced materials could face the risk of uncertainty due to raw material insecurity.

Hard Rock: Attention was also drawn to non-placer and hard rock rare earth deposits within the country. The panel discussed historically identified deposits that have remained unexploited for decades despite exploration. Examples were cited of major discoveries containing significant critical mineral resources. While environmental concerns surrounding extraction and processing, particularly in ecologically sensitive regions, were acknowledged, the panel emphasised that these challenges are manageable through careful siting of processing facilities and adherence to robust environmental safeguards. The broader concern raised was the prolonged delay between discovery and commercialisation, reflecting systemic inertia rather than technical incapacity.

Exploitation: A recurring point of convergence among panellists was the disconnect between exploration and exploitation. While exploration is the fountainhead of mineral mining, it was argued that its value is realised only when discoveries are translated into operational mines.

The panel noted that several proven mineral resources remain unexploited due to procedural bottlenecks. International best practices were cited, where the right to explore is intrinsically linked to the right to mine, thereby incentivising private investment. In contrast, India's reliance on auction-based exploration was critiqued as inherently flawed, given the uncertainty involved in bidding for undiscovered resources.

Questions further explored the regulatory design of exploration licensing, with comparisons drawn to international models where licences can be obtained rapidly through transparent, digital mechanisms and in many cases obtained even online. It was observed that earlier policy frameworks in India had allowed for first-come-first-served access, which many participants felt was logically more suited and conducive to exploration-led investment. The discussion underscored the need for regulatory reforms that balance transparency and a level playing field with geological risk.

Recycling: The session also examined the role of recycling and secondary resource recovery, particularly in relation to lithium-ion batteries used in electric vehicles. Questions were raised about the feasibility of second-life applications for batteries in grid-scale and domestic energy storage systems. It was explained that while short-duration applications may permit the reuse of batteries, most energy storage projects in India are designed for long operational lifespans and require performance warranties that reused batteries cannot reliably provide due to calendar ageing and degradation.

Strategic Importance of Processing and Refining: Finally, the discussion acknowledged the strategic importance of processing and refining capabilities, particularly for minerals such as lithium. The panel noted that while certain deposits are poised for auction, the absence of domestic refining infrastructure will imply continuation of reliance on overseas processing, undermining strategic autonomy. This gap underscores the need for an integrated approach that spans mining, refining, and recycling, rather than isolated interventions at individual stages.

Overall, the widely participated Q&A session reinforced a central message. India possesses the mineral resources, technical expertise and industrial capacity required to secure its critical mineral future to a significant degree. What is lacking is the regulatory agility, policy coherence and timely execution. The session concluded with a clear consensus that unless mineral exploration, mining and processing are addressed in tandem, India risks remaining resource-rich but supply-chain dependent.

CONCLUDING REMARKS

The proceedings concluded with remarks by Air Marshal Philip Rajkumar, PSVM, AVSM (Retd), who was invited to formally close the session. At the outset, he expressed his appreciation to all the speakers and panellists for their insightful and substantive contributions and to the participants for their active engagement throughout the day. He also conveyed special thanks to Dr Nivedita Ray for taking the effort to join the programme and share her perspectives, and to the Indian Council of World Affairs for its collaboration with Asia Centre in jointly hosting the event.

Reflecting on the deliberations, he noted that the audience had been exposed to a wide spectrum of views and a considerable depth of information over the course of the day. Drawing directly from the discussions, he highlighted a few thematic contributions that had particularly stood out. Referring to the conversations on rare earths, he recalled the observation that while the global situation presents clear challenges, there is no immediate need for alarm. This perspective was noted as reassuring and valuable in encouraging measured, long-term policy responses rather than reactive knee-jerk approaches.

He further referred to the discussions on exploration technologies, particularly those emphasising the evolving role of advanced sensing systems and satellite-based tools. The observation that future mineral discoveries may rely less on traditional field methods and more on data-driven, remote technologies was highlighted as a significant shift, with the potential to make exploration faster, more economically viable and environmentally responsible.

Attention was also drawn to the presentations and discussions on battery recycling and resource recovery, which were described as especially timely in the context of the rapid proliferation of electric mobility. These efforts were acknowledged as essential not only from an economic standpoint but also as a strategic and environmental imperative in strengthening critical mineral supply chains.

In his closing remarks, Air Marshal Philip Rajkumar posed a question for the audience to ponder over. He noted the increasing presence of electric vehicles globally and on Indian roads, being touted as a preferred option for reducing emissions.

While recognising that the endpoint, vehicle-level emissions decline with the adoption of electric mobility, he urged participants to examine the emissions generated during the manufacture of batteries. It is important to examine the impact on net lifetime carbon emissions.

With these observations, the event was formally ended.