Securing Rare Earth Metals for India's Aero-Engine Indigenisation

Neha Mishra

India's quest for *Atmanirbharta* in defence and aerospace requires a secure and resilient supply chain of Rare Earth Metals (REMs). With the goal of developing advanced gas turbine engines for fighter jets, Unmanned Aerial Vehicles (UAVs), helicopters, and cruise missiles, one of the key strategies is to advance the value chain of rare earth metals to secure the future advancement of India's aerospace future. Over the last decades, India has achieved advancements in fighter jets such as the Tejas, Advanced Medium Combat Aircraft (AMCA) and naval platforms such as the Scorpene and Arihant classes submarines. However, the continuous import reliance for resources is a key bottleneck in achieving engine indigenisation, most particularly Heavy Rare Earth Elements (HREEs) such as dysprosium, europium, and lutetium, which are required for permanent magnets, superalloys, and thermal barrier coatings.[1] Despite having significant reserves

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1. Ujjwal Shrotryia, "AMCA Approval Notwithstanding, India Still Does Not Have Its Own Jet Engine", *Swarajya*, March 11, 2024, https://swarajyamag.

of Rare Earth Elements (REEs) in Odisha, Tamil Nadu, and Andhra Pradesh, India currently imports more than 90 per cent of its REEs requirement due to limited downstream processing and refining capacity.[2]

The release of the Critical Mineral List (2023)[3] and the recently announced National Critical Mineral Mission seems to be emerging as the key drivers to address the challenges facing India, with a focus on domestic exploration, developing infrastructure for processing capacity, and expand international partnership with resource rich and like-minded nations.[4] With this background in context, the objective of this article is to analyse the role of REMs and the required initiatives for India to promote engine indigenisation, most particularly in the supply chain, industry collaboration, and investment pathways.

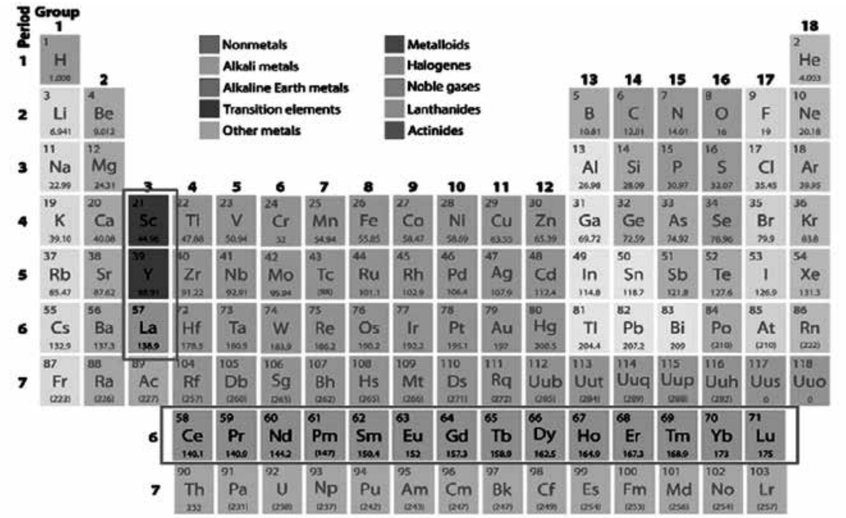
SIGNIFICANCE OF RARE EARTH METALS IN THE AEROSPACE AND DEFENCE SECTORS

REEs are defined as a family of the 'Lanthanide Group', from lanthanum to lutetium (Atomic 57 to Atomic 71) in the periodic table, along with yttrium (Atomic 39) and scandium (Atomic 21), making it a group of 17 elements (see Fig 1).[5]

com/defence/amca-approval-notwithstanding-india-still-does-not-have-its-own-engine. Accessed on February 10, 2025.

2. Ministry of Mines, "Critical Minerals for India", https://mines.gov.in/admin/download/649d4212cceb01688027666.pdf. Accessed on February 10, 2025.
3. Ibid.
4. PIB Delhi, "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", Ministry of Mines, January 29, 2025, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2097309. Accessed on February 14, 2025.
5. Ibid.

Fig 1: REEs in the Periodic Table



Source: Rare Element Resources Limited, "Rare Earth Elements", 2022, https://www.rareelementresources.com/rare-earth-elements. Accessed on August 10, 2023.

It is worth noting that a secured value chain of rare earth elements requires resilience in three main stages: (a) upstream mining, extraction, and separation of rare earth oxide; (b) midstream processing of rare earth metals and alloys; and (c) downstream manufacturing of permanent magnets and end-products. All the stages in the global supply chain are currently being dominated by China. While most countries have upstream and midstream capacities, downstream capacities are still not developed, making it imperative to advance supply chain partnerships among countries.[6, 7]

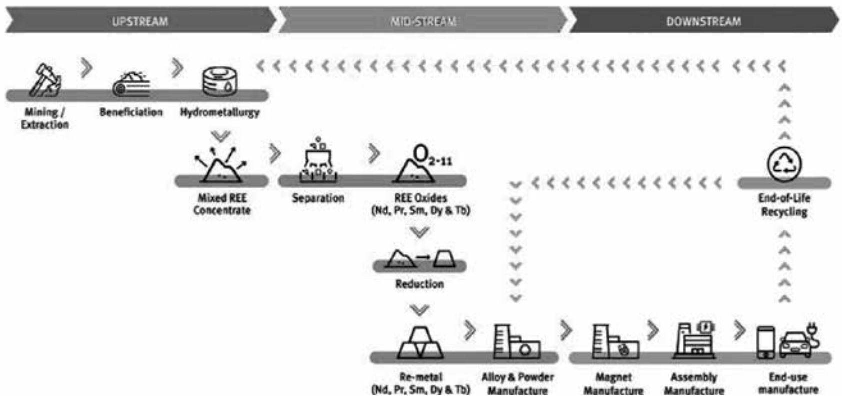
6. Neha Mishra, "India-Australia Rare Earth Supply Chain Collaboration", ORF Expert Speak, July 1, 2023, https://www.orfonline.org/expert-speak/india-australia-rare-earth-supply-chain-collaboration. Accessed on February 11, 2025.
7. Neha Mishra, "Australia's Rare Earth Highway: A Race to Resilience or Dominance?", *Journal of Air Power and Space Studies*, vol. 19, no. 1, Spring 2024 (January-March), https://capsindia.org/wp-content/uploads/2024/04/Neha-Mishra.pdf. Accessed on February 8, 2025.

How Are Rare Earth Metals Processed for Use in Manufacturing?

1. **Extraction:** REEs are extracted from ores through open-pit or underground mining.
2. **Crushing and Milling:** The mined ores are ground into fine particles.
3. **Separation and Refining:** The REEs are separated from other minerals using solvent extraction, ion exchange, or electrochemical processes.
4. **Metal Conversion:** The separated REEs are reduced to metallic form through electrolysis or metallothermic reduction.
5. **Alloying and Component Manufacturing:** The pure rare earth metals are incorporated into superalloys, magnets, coatings, and electronic components.

This complex refining process makes REEs costly and environmentally challenging to produce, reinforcing India's need for domestic processing capabilities.

Fig 2: Process of REE Supply Chain



Source: Rare Earth Industry Association, "Rare Earths", https://global-reia.org/rare-earth/. Accessed on February 20, 2025.

Rare earth metals play a critical role in aerospace and defence technologies, particularly in high-performance engines, electric propulsion, and naval propulsion systems. Their unique magnetic, electrical, and thermal properties make them essential for reducing weight, improving efficiency, and enhancing durability in advanced systems. The application of REEs in modern defence technologies is indispensable, considering their essential properties providing magnetic, optical, and conductive characteristics that advance the operational capabilities of the defence platforms. The specific application of each REE is unique and combines with other REEs as well in the defence and aerospace sector:

1. **Surveillance and Navigational Aids in Naval and Aerial Operations** such as radars and sonar systems require high-sensitivity sensors to improve threat assessment, which gets enhanced by REEs such as gadolinium, samarium, yttrium in terms of detection, tracking, signal processing, and surveillance systems. Examples: sonar transducers, enhanced X-ray radiation detection, Multipurpose Integrated Chemical Agent Detector (MICAD) chemical agent detection systems.
2. **Communication and Display Systems of Advanced Military Electronics** such as lasers and avionics in satellite-based communication networks and infrared targeting systems use dysprosium, europium, neodymium, praseodymium, terbium, and yttrium to advance the signal transmission, secure communication and high-resolution imaging. Examples: laser targeting systems, counter-Improvised Explosive Device (IED) disruptors, laser avenger weapons.
3. **Structural and Mechanical Durability of Armed Vehicle and Tank Mounting Systems** where REEs are used to add resistance and further strength to their stressors and operational reliability in extreme battlefield conditions.

4. **Precision-Guided Munitions and Missile Guidance Systems** such as cruise missiles, anti-ship missiles, and surface-to-air missiles use REEs to develop targeting accuracy, propulsion efficiency, and optimise navigational precision and response time. Examples: Tomahawk cruise missiles, smart bombs, predator drones, Joint Direct Attack Munitions (JDAMs).
5. **Electronic Warfare and Directed Energy Weapons** use REEs for energy storage and density amplification for high-powered electronic warfare systems. Examples: jamming devices, electromagnetic railguns, area denial systems.
6. **Electric Propulsion and Combat Vehicles** use REEs for electric drive motors for hybrid propulsion in military platforms. Examples: Zumwalt-class destroyers, joint strike fighter, hub-mounted electric drive systems.[8, 9]

Given their critical role in modern warfare, securing a stable and sustainable supply of REEs is a strategic imperative for national defence. The increasing reliance on these elements, coupled with the monopolisation of REE production by a few global players, underscores the urgency for reducing import dependencies and developing indigenous rare earth processing capabilities. Establishing domestic supply chains, investing in REE recycling, and forming international strategic partnerships are essential steps in enhancing self-reliance and ensuring long-term security in advanced defence technologies. REEs

8. Redakcja Naukowa and Andrez Trytek, "Materials, Technologies, Constructions: Special Purpose Materials", 2019, https://www.mdpi.com/journal/technologies/special_issues/construction_materials_technologies.
9. Larry M. Wortzel and Kate Selley, "Defense Technology Program Brief: Breaking China's Stranglehold on the U.S. Rare Earth Elements Supply Chain", American Foreign Policy Council, No. 22, https://www.afpc.org/uploads/documents/Defense_Technology_Briefing_-_Issue_22.pdf 2021.

are fundamental to next-generation defence systems, and their availability will significantly influence technological superiority, military readiness, and national security in the evolving global strategic landscape.[10]

CURRENT INITIATIVES FOR AEROSPACE MATERIAL SECURITY IN INDIA

India's import reliance for jet engines is increasingly raising high procurement costs and strategic dependence, including the GE F404 (USA) for the Low Combat Aircraft (LCA) Tejas, AL-31FP (Russia) for the Su-30MKI, and M88 (France) for the Rafale. Although there have been certain significant efforts to develop indigenous projects such as the Kaveri engine, they have faced problems due to the limitation of capital investment, and limited Research and Development (R&D) capabilities, advanced materials, complex engineering and manufacturing.[11]

Over the past decade, India has achieved significant development in advancing its self-reliance in the aerospace materials, with specific focus on improving the manufacturing capacity of aero-engines indigenously. The major contributor for this growth has been the high-performance alloys development by the Gas Turbine Research Establishment (GTRE) under the Defence Research and Development Organisation (DRDO) to reduce import reliance. These advanced material high-performance alloys by GTRE can meet the requirement for next generation gas turbine engines, which include:

(a) Titanium alloys (Ti-6AI-4V), with low weight, high strength, and resistance to high temperature, that can be used for the structure components of aircraft.

10. Naukowa and Trytek, n. 8.
11. Wing Commander Akash Godbole, "Indigenous Jet-Engine Development-India at Crossroads", *CAPS Issue Brief*, February 11, 2025, https://capsindia.org/wp-content/uploads/2025/02/CAPS_IB_AG_11_2_25.pdf. Accessed on February 20, 2025.

(b) Nickel-based superalloys that can provide heat and oxidation resistance to turbine blades, discs, and combustor engine in extreme conditions.
(c) Specialised steels that can be used in the low-temperature engine section and supporting structures to ensure high strength and durability.[12]

GTRE is already conducting ground tests of these alloys to validate their high performance and durability, with the objective of meeting the demands of the Kaveri engine to attain the target thrust capabilities up to 80Kn (kilonewton). To enhance efficiency, GTRE has also planned to engage retired defence personnel for technical schemes to support material characterisation and testing activities.[13] GTRE has attracted interest from 25 Indian defence companies eager to partner with foreign Original Equipment Manufacturers (OEMs) on new engine development projects, including the AMCA programme.[14]

Besides GTRE, the Aero-Engine Research and Development Centre (AERDC) of Hindustan Aeronautics Limited (HAL) is developing the design of two strategic new engines:

(a) The Hindustan Turbo Fan Engine (HTFE) with 25Kn thrust for powering small fighter aircraft, regional jets, and UAVs.
(b) The Hindustan Turbo Shaft Engine (HTSE) with 1,200Kn thrust for powering light and medium weight helicopters.

12. "GTRE To Test TI-Alloys, Ni-Based Superalloys, And Steels For Aero-Engines", *Indian Defence News*, December 19, 2024, https://www.indiandefensenews.in/2024/12/gtre-to-test-ti-alloys-ni-based.html. Accessed on February 2, 2025.
13. "GTRE DRDO Proposes Engagement of Retired Defence Personnel for Aeroengine Material Testing", *Indian Defence Research Wing*, December 23, 2024, https://idrw.org/gtre-drdo-proposes-engagement-of-retired-defense-personnel-for-aeroengine-material-testing/. Accessed on February 3, 2025.
14. Raunak Kunde, "25 Companies Eager to Partner with GTRE for New Engine Development", Indian Defence Research Wing, February 8, 2025, https://idrw.org/25-companies-eager-to-partner-with-gtre-for-new-engine-development/. Accessed on February 3, 2025.

In 2023, the AERDC inaugurated a new design and test facility that involves an in-house fabrication facility, two test-beds for testing the HTFE-25 and HTSE-1200, an upcoming Joint Venture (JV) engine for the Indian Multi-Role Helicopter (IMRH) to be co-developed by Safran and HAL.[15]

Taking the recent initiatives into account, at Aero India 2025, HAL inaugurated the first look of the AMCA prototype and entered into a long-term contract with Safran Aircraft Engines (SAE) for the supply of turbine forged parts for their Leading-Edge Aviation Propulsion (LEAP), which marks the first step under their industrial cooperation Memorandum of Understanding (MoU) in commercial engine parts manufacturing to advance India's "Make in India" policy.[16] In addition, Bharat Forge unveiled its first fully indigenous UAV engine with a thrust capacity of upto 400 Kgf (kilogram-force), and also highlighted its production capacity of landing gears that aims to potentially enter to support the AMCA's production.[17]

LIMITATIONS OF INDIA'S REE ECOSYSTEM

Despite having 6 per cent of global rare earth reserves, India has less than 1 per cent of global total production capacity, which

15. "HAL Gets New Design & Test Facility for HTFE-25, HTSE-1200 and IMRH Engine", *Indian Defence Analysis*, December 29, 2023, https://indiandefenseanalysis.wordpress.com/2023/12/29/hal-gets-new-design-test-facility-for-htfe-25-htse-1200-imrh-engine/. Accessed on February 4, 2025.
16. "HAL Inks Long-Term Pact for LEAP Engine Components with Safran Aircraft", *Business Standard*, Press Trust of India, February 12, 2025, https://www.business-standard.com/external-affairs-defence-security/news/hal-inks-long-term-pact-for-leap-engine-components-with-safran-aircraft-125021201759_1.html. Accessed on February 16, 2025.
17. Sarahbeth George, "Bharat Forge Takes a Major Step Towards Closing One of India's Biggest Defence Gaps", *The Economic Times*, February 19, 2025, https://economictimes.indiatimes.com/news/defence/bharat-forge-takes-a-major-step-towards-closing-one-of-indias-biggest-defence-gaps/articleshow/118350247.cms. Accessed on February 20, 2025.

continues its reliance heavily on imports for several critical minerals essential to key industries, including energy storage, defence, and advanced manufacturing (see Table 1).[18] Although the Ministry of Mines and Geological Survey of India (GSI) have sanctioned hundreds of exploration projects in the last three years, for instance, in Jammu and Kashmir (J&K) and Andhra Pradesh, the cycle from "mines to metals" still requires improvement in India's technical capacity and regulatory affairs. India requires advanced metallurgy to develop its midstream processing and downstream manufacturing, which are currently non-existent, providing few rare earth separation plants.[19]

Table 1: India's Import Dependence for Critical Minerals

Mineral	**Import Source Countries**	**Major Application Sector**
Lithium	Chile, Russia, China, Ireland, Belgium	Rechargeable Batteries
Cobalt	China, Belgium, Netherlands, US, Japan	Superalloys for Magnets and Cutting Tools
Nickel	Sweden, China, Indonesia, Japan, Philippines	Stainless Steel
Vanadium	Kuwait, Germany, South Africa, Brazil, Thailand	Steel Alloys
Niobium	Brazil, Australia, Canada, South Africa, Indonesia	Steel and Jewelry
Germanium	China, South Africa, Australia, France, US	Semiconductors

18. Nayan Seth, "Rare Earths, Rare Opportunity: India's Potential in Easing China's Chokehold", *South Asian Voices*, October 23, 2024, https://southasianvoices.org/ec-m-in-n-us-india-rare-earths-10-23-2024/#:~:text=Despite%20having%20around%20six%20percent,enter%20the%20rare%20earth%20market. Accessed on February 20, 2025.
19. Ministry of Mines, "National Policy on Critical Minerals", Sansad.in December 4, 2024, https://sansad.in/getFile/loksabhaquestions/annex/183/AU1425_kdExgm.pdf?source=pqals#:~:text=subsidiary%20company%20or%20invest%20in,Pacific%20Economic%20Framework%20%28IPEF. Accessed on February 20, 2025.

Rhenium	Russia, UK, Netherlands, South Africa, China	Petroleum Refining
Beryllium	Russia, UK, Netherlands, South Africa, China	Alloying Agent in Defence Equipment
Tantalum	Australia, Indonesia, South Africa, Malaysia, US	Electronic High-Power Resistors and Capacitors
Strontium	China, US, Russia, Estonia, Slovenia	Alloys of Aluminum, Magnets, and Pyrotechnic Application

Source: Ministry of Mines, "Critical Minerals for India", https://mines.gov.in/admin/storage/app/uploads/649d4212cceb01688027666.pdf. Accessed on September 8, 2023.

The exclusive right to mine and process monazite-bearing beach sands by a state-owned enterprise, Indian Rare Earths Limited (IREL), and continuous restriction on private companies until 2023, limited the innovation and investments progress in India's midstream and downstream industries.[20] Moreover, the concentration of a radioactive element thorium (Th) in monazite beach sands increases the concerns around radioactive waste management.[21] The mining and process also entail environmental issues for the local population, since the use of chemical processing generates toxic tailing that can impact the groundwater and marine ecosystems.[22]

INDIA'S STRATEGIES FOR SECURING RARE EARTH METALS

Given the supply chain challenges, India needs to implement a multi-faceted approach to strengthen its domestic mining-

20. D. Chakravarty, and A. Chandrasekaran, "India's Rare Earth Conundrum: Challenges and Opportunities", *Journal of Resource Policy*, vol. 72, 102019. Accessed on February 20, 2025.
21. R. Gopalakrishnan, "Challenges in Thorium Waste Management From Rare Earth Extraction", *Journal of Nuclear Materials Management*, vol. 48(3), pp. 112-126.
22. S. Banerjee, P. Reddy, and D. Kulkarni, "Radioactive Waste Management in India's Rare Earth Sector: An Assessment of Policy Gaps", *Environmental Monitoring and Assessment*, vol. 192, 335. Accessed on February 25, 2025.

processing capabilities and develop international partnerships. One of the key strategies here is to expand the global partnerships with like-minded, resource-rich nations to reduce import reliance on a single supplier and facilitate transfer of technology.

On the international partnership front, India has prioritised its critical mineral association with multilateral initiatives such as the Quadrilateral Security Dialogue (Quad), Mineral Security Partnership (MSP), G20, and others. The Quad 2.0, comprising Australia, India, Japan, and the United States, has prioritised securing the global supply chain and markets of critical minerals, with its key initiatives like the Quad Critical Mineral Partnership Act (2022)[23] and Quad Investors Network[24] that are promoting knowledge sharing, joint ventures, and co-investment prospects, thus, further collaboration with Quad members for India. Taking the case of MSP, India's participation in this US-led initiative has expanded its access to global investments, overseas project for partnerships, and mining ventures, thus, ensuring long-term resource security as well as advancing domestic refining and manufacturing capabilities.[25] At the G20 summit, India actively brought critical minerals security as the centre of discussion during its presidency in 2023 and even introduced the 'High-

23. Abhishek Sharma, "The Case for a Quad Mineral Security Partnership", *ORF Issue Briefs*, October 30, 2024, https://www.orfonline.org/research/the-case-for-a-quad-mineral-security-partnership?utm_source=chatgpt.com. Accessed on February 20, 2025.
24. Alex El-Fakir, "Quad Investors Network 'Instrumental' In $650M U.S. Investment by India's Epsilon Advanced Materials", *Business Wire*, November 14, 2023, https://www.businesswire.com/news/home/20231114023513/en/Quad-Investors-Network-Instrumental-In-650M-U.S.-Investment-by-Indias-Epsilon-Advanced-Materials?utm_source=chatgpt.com. Accessed on February 21, 2025 .
25. Siddharth Pruthi, "How India Joining the Mineral Security Partnership Will Boost Its Critical Mineral Drive", Council on Energy, Environment and Water, October 17, 2023, https://www.ceew.in/blogs/how-india-joining-mineral-security-partnership-will-boost-critical-minerals-supply-chain. Accessed on February 22, 2025.

level Principles for Collaboration on Critical Minerals', to support equal access to minerals, reduce import reliance, and develop a circular economy.[26] At the trilateral level, India co-founded the Supply Chain Resilience Initiative with Japan and Australia in 2021, with the objective of knowledge sharing and working on joint projects to explore alternative sources to develop supply chain diversification.[27] At the bilateral level, India has cemented certain strategic partnerships with Australia, the USA, Japan, France, UK, Argentina, Chile, Brazil, and others. The significant bilateral partnerships are:

(a) **India-Australia Critical Minerals Investment Partnership:** which aims to combine the mining expertise of Australia with India's market capabilities through focussing on five projects (two lithium and three cobalt).[28]

(b) **India-US Memorandum of Understanding (MoU) to Expand and Diversify Critical Mineral Supply Chains:** which intends to combine both countries' strengths in exploration, mining, processing, and recycling of critical minerals.[29]

26. Ministry of External Affairs, "G20 New Delhi Leaders' Declaration", September 9-10, 2023, https://www.mea.gov.in/Images/CPV/G20-New-Delhi-Leaders-Declaration.pdf#:~:text=ix,Critical%20Minerals%20for%20Energy%20Transitions%E2%80%9D. Accessed on February 23, 2025.
27. Dhanasree Jayaram and C.M. Ramu, "India's Critical Minerals Strategy: Geopolitical Imperatives and Energy Transition Goals", Finnish Institute of International Affairs, April 2024/386, https://www.fiia.fi/wp-content/uploads/2024/04/bp386_indias-critical-minerals-strategy.pdf#:~:text=match%20at%20L436%20India%2C%20Japan%2C,fortify%20India%E2%80%99s%20col%02laborations%20with%20its. Accessed on February 23, 2025.
28. Department of Foreign Affairs and Trade (Australian Government), "Bolstering our Ties with India", https://www.dfat.gov.au/geo/india/bolstering-our-ties-india#:~:text=%2A%20An%C2%A0Australia,and%20working%20with%20India%20to. Accessed on February 23, 2025.
29. PIB Delhi, "India and US Sign MoU to "Expand and Diversify Critical Mineral Supply Chains", Ministry of Commerce and Industry, October 4, 2024, https://pib.gov.in/PressReleasePage.aspx?PRID=2062127#:~:text=Under%20

(c) **India-Argentina Agreement on Critical Mineral Exploration and Technology:** which has brought Indian public and private entities (KABIL, Coal India) to explore lithium blocks in the Catamarca province of Argentina.[30]

On the domestic front, the amendment in the Mines and Minerals (Development and Regulation) Act (1957) in 2023 has expanded the participation of private industry in the auctioning of exploration projects. Over the last three years, the Geological Survey of India (GSI) has conducted around 368 exploration projects. The Ministry of Mines has also introduced the Science and Technology- Promotion of Research and Innovation in Startups and MSMEs (S&T PRISM) programme that aims to bridge the gap between R&D and its commercial aspects. In addition, the recently launched National Critical Mineral Mission (NCMM) aims to expand all stages of the critical mineral value chain in India, starting from exploration, mining, processing, and recycling from end-of-life products. The aims of the mission are the exploration of critical minerals within the country as well as in offshore areas, through fast tracking the regulatory approval process, financial incentives by promoting R&D in critical minerals, and supporting recycling of critical minerals. It has also proposed to set up a Mineral Processing Parks and a Centre of Excellence on Critical Minerals.[31] Additionally, collaborations among HAL, DRDO,

the%20Supply%20Chain%20track%2C,processing%2C%20recycling%2C%20and%20related%20activities. Accessed on February 23, 2025.

30. "India Seeking Energy, Lithium Investments in Argentina", Reuters, January 29, 2025, https://www.mining.com/web/india-seeking-energy-lithium-investments-in-argentina/#:~:text=Indian%20state%20firms%20Khanij%20Bidesh,on%20the%20border%20with%20Chile. Accessed on February 24, 2025.
31. PIB Delhi, "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", Ministry of Mines, January 29, 2025, https://pib.gov.in/PressReleaseIframePage.

Mishra Dhatu Nigam Limited (MIDHANI), Tata Advanced Systems, and Bharat Forge are strengthening domestic research on high-performance materials for aero-engines, electric propulsion, and defence applications.

WAY FORWARD FOR INDIA

These initiatives have been instrumental in reducing reliance on foreign suppliers for aerospace and defence applications. A stable supply of nickel and cobalt superalloys is essential for India's AMCA and Kaveri engine programme, while titanium, rare earth magnets, and superalloys are vital for warship gas turbines and electric propulsion systems in submarines. Additionally, securing lithium, cobalt, and nickel through international partnerships supports India's Production Linked Incentive (PLI) scheme for battery manufacturing and energy transition objectives.

Despite these advancements, India faces several challenges, including limited mining and processing capacity, infrastructure gaps, and slow technological progress in areas such as REE separation and lithium refining. While international collaborations help diversify supply sources in the short term, scaling up domestic exploration, refining, and metallurgical R&D remains a priority. Addressing these gaps will be crucial for India to achieve self-reliance in critical materials, strengthen its aerospace and defence sector, and reduce strategic vulnerabilities. By pursuing a multi-pronged strategy encompassing domestic reforms, strategic stockpiling, and global alliances, India is positioning itself as a key player in the global critical minerals supply chain, ensuring the successful indigenisation of high-tech defence and aerospace technologies.

aspx?PRID=2097309&utm_source=chatgpt.com. Accessed on February 21, 2025.