UNLOCKING AUSTRALIA-INDIA CRITICAL MINERALS PARTNERSHIP POTENTIAL

INDIA CRITICAL MINERALS DEMAND REPORT

JULY 2021

Australian Government
Australian Trade and Investment Commission

AIBX
Australia India Business Exchange

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Austrade

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CONTENTS

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We also thank those across the Australian and Indian industries whose insights and guidance have helped us shape this report.

FIGURES

TABLES

#Average Annual Exchange Rate (2020) of 1 US$ = 1.45 A$ and 1 A$ = 51.14 INR (https://ofx.com) has been consistently used across document for conversion wherever applicable.

ABBREVIATIONS

Abbreviation	Description
ARCI	International Advanced Research Centre for Powder Metallurgy and New Materials
BARC	Bhabha Atomic Research Centre
BCD	Basic Customs Duty
BESS	Battery Energy Storage Systems
CAGR	Compounded Annual Growth Rate
CEEW	Council on Energy, Environment and Water
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DRC	Democratic Republic of Congo
EDR	Economic Demonstrated Resources
ESS	Energy Storage System
EV	Electric Vehicle
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FS	Feasibility Study
GDP	Gross Domestic Product
GWh	Gigawatt Hour
HCL	Hindustan Copper Limited
HREE	Heavy Rare Earth Elements
IBM	Indian Bureau of Mines
IGST	Integrated Goods and Services Tax
IREL	Indian Rare Earths Limited
JV	Joint Venture
KABIL	Khanij Bidesh India Limited
KMML	Kerala Minerals and Metals Limited
kt	Kilo Tonnes
kWh	Kilowatt Hour
LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
LME	London Metal Exchange
LREE	Light Rare Earth Elements
METS	Mining Equipment, Technology and Services
MIDHANI	Mishra Dhatu Nigam Limited
MNRE	Ministry of New and Renewable Energy
MOU	Memorandum of Understanding
MSMEs	Micro, Small, and Medium Enterprises
MT	Metric Tonnes
Mt	Million Tonnes
MW	Megawatt
NALCO	National Aluminium Company Limited
NdFeB	Neodymium Iron Boron
NdPr	Neodymium and Praseodymium
NCA	Lithium Nickel Cobalt Aluminium Oxide
NMC	Lithium Nickel Manganese Cobalt
NMDC	National Mineral Development Corporation
OEM	Original Equipment Manufacturer

Abbreviation	Description
PFS	Pre-feasibility study
PGM	Platinum Group Metals
PLI	Production Linked Incentive
PMAY	Pradhan Mantri Awas Yojna
R&D	Research and Development
REE	Rare Earth Element
RIL	Reliance Industries Limited
SmCo	Samarium Cobalt
SMEs	Small and Mid-sized Enterprises
SPG	Spherical Graphite
SWS	Social Welfare Surcharge
TDSG	TDS Lithium-ion Battery Gujarat Private Limited
TGC	Total Graphitic Carbon
UKTMP JSC	Ust-Kamenogorsk Titanium and Magnesium Plant Joint Stock Company
VRFB	Vanadium Redox Flow Batteries
ZEV	Zero Emission Vehicles

FOREWORD

Australia and India share a close, long-standing and multi-faceted relationship in the resources sector. To date this has featured bulk commodity and energy mineral exports from Australia and extensive links in mining equipment, technology and services (METS). Australian METS capabilities have supported productivity and efficiency gains across India's mining industry.

In June 2020, Australia and India elevated their bilateral relationship to a Comprehensive Strategic Partnership.

At that time, Australia's Department of Industry, Science, Energy and Resources and India's Ministry of Mines signed a memorandum of understanding (MOU) on increasing trade, investment and research and development in critical minerals between the two countries.

To take forward cooperation the two sides formed a joint working group comprising government, industry and research institution representatives, tasked with facilitating institutional and commercial partnerships to support stable and resilient supply chains for critical minerals.

As part of the MOU work plan, the Australian Trade and Investment Commission (Austrade) commissioned Deloitte Touche Tohmatsu LLP India to prepare a report on India's current and future demand for critical minerals in India and potential opportunities for cooperation with Australia.

This report is intended to provide industry and government with guidance on market dynamics and bilateral commercial cooperation opportunities across the critical minerals supply chain.

This report has been produced as part of the Australia India Business Exchange (AIBX). AIBX is the Australian Government's flagship program to increase partnerships and engagement between Australian and Indian businesses.

As the Australian Government's trade and investment promotion agency, Austrade seeks to facilitate international investment, offtake, technology and research partnerships for critical minerals.

Austrade uses its extensive offshore network and partnerships across government and industry to grow Australian exports and attract productive foreign investment into Australia.

Interested critical mineral investors, project proponents and other industry and government stakeholders can contact Austrade via our website (www.austrade.gov.au) or through one of our offshore offices.

EXECUTIVE SUMMARY

Critical minerals are essential inputs for many high-demand manufactured products.

Critical minerals have diverse applications, from metallurgy and chemical industries to energy storage systems (ESS) for renewable energy, electric mobility, power generation, high-end electronics, aerospace, defence, and data transmission hardware.

The economic importance of critical minerals for these industries, along with risks to stable supply, make them strategically valuable.

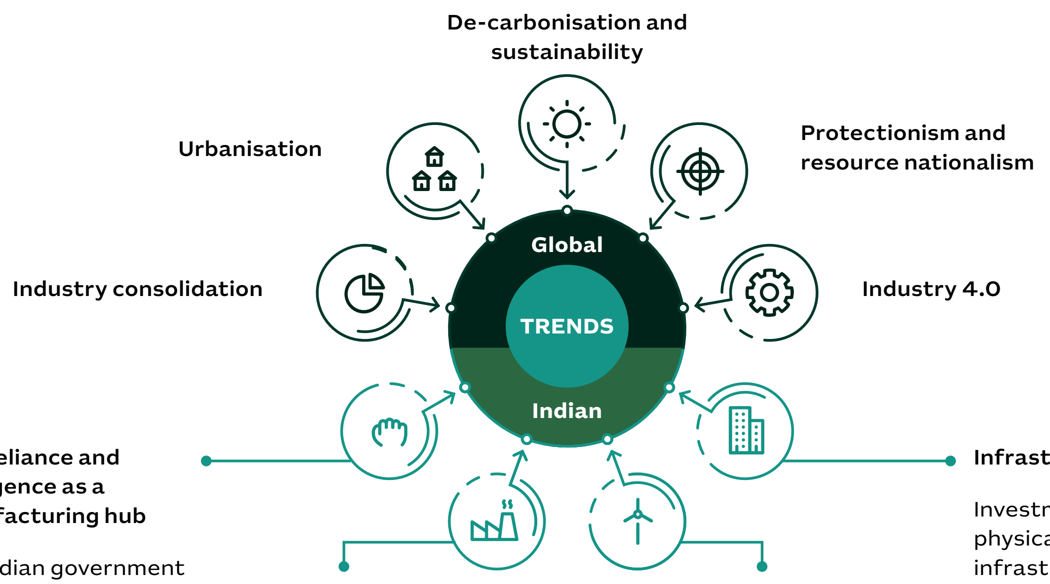
Over the next decade, economic megatrends are forecast to drive higher global demand for critical minerals and processing technologies.

India has an ambitious industrial reform agenda to expand manufacturing capability and to transition to a low-carbon and digitised economy.

This includes plans for rapid expansion of electric mobility and renewable energy generation, as well as enhanced capability across high-technology sectors.

These are among the key drivers for India in seeking to source stable and secure supply of critical minerals and related processing and refining technologies.

Figure 1: Key megatrends for 2030[1]



Self-reliance and emergence as a manufacturing hub

The Indian government has launched ambitious projects, such as Atmanirbhar Bharat and Make in India. As part of the Atmanirbhar Bharat, the PLI scheme was recently introduced for multiple sectors that includes ambitious plans for traditional sectors.

Renewable energy and battery storage

The government has set an ambitious target to achieve 175GW by 2022 and 450GW renewable energy by 2030. Batteries will enable current energy transition towards electric mobility, integration of renewable energy through grid scale storage, and improved energy access in India.

Resource efficiency and circular economy

Transition to production is seen through the recycled route and utilisation of process waste entails lower carbon emissions, and resource and energy consumption.

Infrastructure

Investments in physical and digital infrastructure via the smart cities mission, PMAY, and digital India will be instrumental in meeting needs of connectivity and urbanization.

Notes:

1. Secondary Research and Industry sources

Eight mutually important minerals

This report identifies a shortlist of eight critical mineral categories that are mutually important to both Australia and India.

The shortlist was formulated based on findings of the *Australian Critical Minerals Prospectus 2020, Critical Minerals Projects in Australia 2020* and Indian government reports such as *Critical Non-Fuel Mineral Resources for India's Manufacturing Sector.*

These reports, as well as extensive industry stakeholder consultations, have provided data on Indian demand projections and Australian supply capabilities, allowing us to develop a list of mutually relevant critical minerals.

The eight minerals considered to be of greatest mutual interest are lithium, cobalt, nickel, graphite, light rare earth elements (LREEs), heavy rare earth elements (HREEs), titanium and vanadium.

These have been classified into three categories based on their end-use industries:

- traditional – titanium and vanadium
- sunrise – lithium
- mixed use – cobalt, nickel, graphite, LREEs and HREEs.

This report also evaluates:

- India's and Australia's resource potential
- India's and Australia's exploration, mining and mineral processing capabilities
- projected demand from downstream sectors in India.

In relation to Australia, the report also examines:

- near-term supply capabilities of operating mines and processing facilities
- future mining and processing projects
- required investments and technologies
- the possibility of sourcing technologies from third countries
- pricing dynamics.

Outlook for traditional sectors

India has a mature and globally significant metallurgical industry and is the second-largest producer of steel and stainless steel globally. It also has significant electric arc furnace based steel making capacity.

India has a large industrial base that includes mechanical, chemical, electrical, automotive and defence production.

India's titanium demand will be driven by rapid urbanisation and related requirements for paints and other titanium-based products.

India currently does not have downstream capacity for titanium metals or alloys as it lacks commercial-scale local technologies to produce titanium products.

India also continues to be reliant on imports for vanadium.

Manufacturers of ferroalloys and master alloys, which are catalysts for chemical and vanadium redox flow batteries (VRFB), are among the consumers of vanadium, but India does not have economically viable domestic resources.

Outlook for sunrise and mixed-use sectors

The Indian Government has implemented policy reforms to accelerate new low-carbon sectors such as renewable energy, energy storage and electric mobility. This agenda is overseen by the Ministry of New and Renewable Energy (MNRE).

The Indian Government's ambitious industrial self-sufficiency and growth program, Atmanirbhar Bharat (Self-Reliant India), includes production-linked incentives for multiple sunrise sectors such as advanced chemistry cell battery storage for electric vehicles.

India aims to have 30 percent of vehicles powered by electricity by 2030. India has invested INR 100 billion (A$ 1.95 billion) in the Faster Adoption and Manufacturing of Electric Vehicles in India (FAME II) initiative, allocating 86 percent to incentives and 14 percent to vehicle charging infrastructure, as per the Department of Heavy Industry, Ministry of Heavy Industries and Public Enterprises, Government of India.

As per IEA (International Energy Agency), India plans to develop 50 Gigawatt hours (GWh) of cell manufacturing capacity by 2025 but its lithium-ion battery manufacturing capability is currently limited. Existing manufacturers import lithium-ion cells to make batteries.

It is estimated that by 2030 India's total demand for lithium-ion batteries will reach about 492 GWh.[2] Demand will be driven by grid-scale storage and EVs, which together are expected to account for almost 98 percent of the overall storage requirements.

This will also create strong demand for permanent magnets (magnets that produce a permanent magnetic field) and related products.

India's lithium-ion battery manufacturing capability is currently limited and existing manufacturers are largely reliant on imports.

As a result, India plans to establish significant downstream capacity for EVs and lithium-ion batteries, as well as modest capacity for permanent magnets.

The Indian government's premier policy think tank, NITI Aayog, formulated a policy framework for Zero Emission Vehicles (ZEVs) to develop an EV ecosystem for energy efficient low-emission vehicles.

India will also need to develop capability for recycling and recovery of active materials (special chemicals applied to electrodes in battery cells) from spent batteries.

India's demand for LREEs and HREEs – including neodymium, praseodymium, samarium and dysprosium – is expected to be driven by the permanent magnet and related high-technology industries.

But India's midstream and downstream REE value chains are not well developed and India is dependent on imports of rare earth magnets, including neodymium magnets, which are the most widely used.

India's critical minerals value chain will evolve over the coming decade but progress will depend on factors such as technology availability, viability of processing at mines, user facilities in India, availability of finance and risk appetite.

Notes:

2. Total EV sales 2020-2030: 2W: 65 Mn, 3W: 3.9 Mn, 4W passenger: 4.3 Mn, 4W commercial: 0.53 Mn, Buses: 84,000; Battery size: 2W: 2kWh, 3W: 6kWh, 4W passenger: 40kWh, 4W commercial: 60kWh, Buses: 200kWh; Grid scale storage – As estimated by Central Electricity Authority for optimal generation mix 2029-30 (Scenario I); storage size in "others" category is calculated assuming a minimum 20% battery penetration; 80% depth of discharge is assumed to calculate battery size. This estimate does not include demand from consumer electronics, UPS and data centres

Figure 2: Demand and supply dynamics for priority critical minerals by 2030[3]

Demand and supply				End-use industry#	Key impediments to future growth
Lithium Battery Mineral	Demand	2020e ~1 kt	2030f **62-109 kt#**	EV and ESS **91%**; Others* **9%**	Reliance on the import of raw materials or intermediate materials
	Supply	**100% import dependence**		*others include ceramics and paint	Sizeable investments to set up battery and cell manufacturing facilities
Cobalt Battery Mineral	Demand	2020e ~1 kt	2030f **88-165 kt#**	EV and ESS **78%**; Others* **22%**	Global players' willingness to collaborate and transfer technologies to Indian firms
	Supply	**100% import dependence**		*others include superalloys, magnets, and pigments	
Graphite Battery Mineral**	Demand	2020e ~167.8 kt	2030f **2806-3720.5 kt#**	EV and ESS **26%**; Electrodes **37%**; Refractories **22%**; Others * **15%**	Limited long-term technology investments to develop next-generation battery technologies and cell manufacturing
	Supply	**60% import dependence**		*others include foundries and lubricants	
Nickel Battery Mineral	Demand	2020 ~61.3 kt	2030f **1228.9-1484.2 kt#**	Stainless Steel **75%**; EV, ESS, other batteries **23%**; Others * **2%**	Lack of robust supply chain networks due to limited partnerships with other countries
	Supply	**100% import dependence**		*others include alloys, chemicals, and coinage	
Ilmenite, Rutile Titanium bearing minerals	Demand	2020e ~200 kt	2030f **3120-3870 kt#**	Chemicals, paint, and pigments **99%**; Others* **1%**	Access to suitable technologies for conversion of ilmenite and rutile into titanium sponge or metal
	Supply	**Significant import dependence in titanium dioxide, sponge, and metal**		*others include ceramics, electrodes, and paper	
Light rare earths##	Demand	2020e ~1.1 kt	2030f **13-28 kt#**	EV **87%**; Wind **8%**; Others* **5%**	Limited capacity additions in intermediate value chain such as REO to metal or magnets
	Supply	**100% import dependence in magnets, limited capacity in processing of oxides**		*others includes ICE & electronics	Limited reserves of heavy rare earth and lack of commercial scale technology for HREE processing
Heavy rare earths###	Demand	2020e ~68 t	2030f **1297-3687 kt#**	EV **95%**; Others* **5%**	Limited technology investments to develop the manufacturing ecosystem for end-use applications
	Supply	**100% import dependence in downstream products and limited HREE resources**			
Vanadium	Demand	2020 ~3 kt	2030f **65-87 kt#**	Steel **85%**; Others* **15%**	Low growth of special steel consumption, no primary production despite resources in India
	Supply	**100% import dependence**		*others include VRFB , master alloys, pigments, and dyes	

represents cumulative demand numbers for 2030; **includes natural and synthetic graphite demand
indicates demand for NdPr ### indicates demand for Dy

Notes:

3. Information referred to from individual deep dive section for each mineral

Indian Government's downstream industry policy initiatives

The Indian Government launched **Make in India**[4] in 2014 as a program to facilitate industrial investment, foster innovation, enhance skill development and to position India as a global manufacturing hub.

Make in India aims to increase the manufacturing sector's contribution to national GDP to 25 per cent by 2025. It focuses on a range of sectors including several key downstream industries in the critical minerals supply chain such as automotive, renewables, electronics and defence.

To accelerate industrial and economic development, in 2020 India launched Aatmanirbhar Bharat (self-reliant India) with the dual aims of fast-tracking modern infrastructure development and increasing India's attractiveness as a destination for global investors.

Indian authorities have adopted a number of measures under these two initiatives that will support critical minerals downstream industry growth, including the following.

Production-linked incentive (PLI) scheme[5]

The PLI scheme seeks to create global champions in manufacturing and reduce dependence on import of finished goods. It offers output-based financial incentives for both greenfield and brownfield projects.

In its 2021-22 budget, the Indian Government provided INR 1.97 lakh crore (A$38 billion) for the PLI scheme in 13 key sectors including electronics, automotive, energy storage, steel and telecommunications.

The scheme provides on average 5 percent of production value as an incentive and includes conditions around minimum production scale.

National Electric Mobility Mission Plan 2020 (NEMMP)[6]

This plan focuses on national energy security, reducing the carbon footprint of the transport sector, and supporting electric vehicle manufacturing capability.

Faster Adoption and Manufacture of Hybrid and Electric Vehicles (FAME)[7] **scheme**

As part of the NEMMP, India's Department of Heavy Industry adopted the FAME scheme to promote electric and hybrid vehicle technology manufacturing.

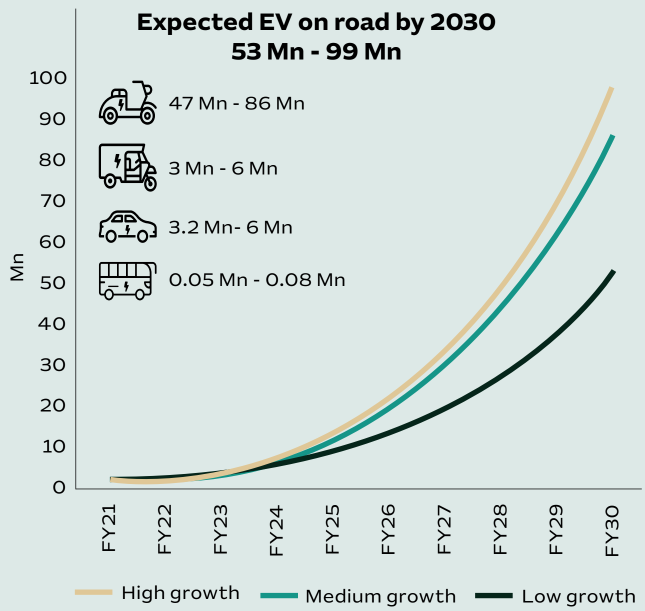
FAME II provides INR 10,000 crore ($A2 billion) over three years from 2019 to promote production of electric two wheelers, three wheelers and buses. FAME is also supporting construction of 2,700 charging stations, primarily in major cities.

National Mission on Transformative Mobility and Battery Storage[8]

The Indian Government's policy think tank NITI Aayog is leading this project that aims to support establishment of a large scale, export-competitive battery and cell manufacturing industry.

NITI Aayog is coordinating with industry to ensure a cohesive and robust policy framework is in place to drive growth in the sector.

Figure 3: India's EV market scale by 2030



Notes:

4. https://www.makeinindia.com/atmanirbhar-bharat-abhiyaan#:~:text=The%20government's%20goal%20is%20to,5%20Tn%20economy%20by%202025.&text=Infrastructure%20%2D%20which%20will%20become%20India's,over%20the%20next%20five%20years.
5. https://www.investindia.gov.in/team-india-blogs/production-linked-incentive-pli-scheme-decoded
6. https://dhi.nic.in/writereaddata/content/nemmp2020.pdf
7. https://fame2.heavyindustry.gov.in
8. https://www.investindia.gov.in/team-india-blogs/opportunities-ev-battery-and-cell-manufacturing-india

Opportunities for Australia-India cooperation

India's projected demand for critical minerals presents significant opportunities to increase cooperation with Australia.

India offers Australian critical minerals producers economies of scale for offtake arrangements, and a robust pipeline of manufacturing-led commercial innovation opportunities.

With its abundant critical mineral reserves and world-class mining expertise, Australia can assist India to achieve its industrial growth goals.

Australian companies and institutions can evaluate models to:

- supply processed minerals
- export services and technology for processing, refining, recovering and recycling critical minerals
- support mineral exploration and mining-related environmental management in India
- establish joint research projects across the value chain.

Austrade can assist with tailored introductions between companies and provision of market insights to businesses on both sides.

Indian firms are exploring investment opportunities in Australian mining and mineral processing assets.

The Indian government's critical minerals sourcing agency, Khanij Bidesh India Limited (KABIL), and the Australian Government's Critical Minerals Facilitation Office (CMFO), along with Austrade, can support investment facilitation.

There is also an opportunity for third country involvement in the value chain to enhance supply chain efficiency and resilience, and particularly to address capability gaps in intermediate mineral processing.

The Australia-India Joint Working Group (JWG) on critical minerals established under the bilateral memorandum of understanding (MOU) on critical minerals will support policy exchange and cooperation and facilitate linkages between business and research institutions.

RECOMMENDATIONS

Based on the findings of this report, we offer the following recommendations to progress Australia-India critical minerals commercial partnerships. These recommendations cover actions both by Austrade and by partners across government and industry.

1. **Increase understanding of commercial opportunities and pathways to partnership**
    - Austrade and partners to develop tailored market insights for Australian businesses on cooperation with India for individual minerals and supply chains, particularly in sunrise sectors where market understanding is comparatively low.
    - Austrade to continue mapping key Indian critical mineral and downstream customers, particularly in sunrise sectors, to assist Australian businesses in identifying opportunities.
    - Austrade and partners such as Australia Minerals, the Confederation of Indian Industry (CII) and the Federation of Indian Chambers of Commerce and Industry (FICCI) to continue delivering industry showcases and roundtables to improve understanding of commercial opportunities across industry and government.
    - Australia-India JWG on critical minerals to sharpen its focus on facilitating commercial outcomes by including key industry stakeholders in working group dialogue and supporting connections between companies.

2. **Identify and facilitate opportunities for Indian investment in Australian mining and mineral processing projects**
    - CMFO to establish a strategic framework with KABIL to support opportunities for Indian investment in Australian critical minerals exploration, mining and processing.
    - Both sides to agree through the JWG a clear investment focus such as joint development of mineral processing capability for the battery value chain.
    - Investors and target companies to explore government funding and support arrangements including through seed funding, export finance and facilitation of offtake arrangements.
    - Investors and target companies to examine other government support through initiatives such as the Modern Manufacturing Initiative, Northern Australia Infrastructure Facility and state government programs.

3. **Pursue mineral offtake partnerships**
    - Austrade to facilitate targeted matching for Australian critical minerals project proponents with Indian customers for offtake partnerships, noting Australia's emerging capacity for lithium processing and that early offtake opportunities are particularly prospective for traditional industries such as metals, paints and chemicals.
    - Australian project proponents in the eight identified mineral categories to consider government support programs that would facilitate offtake arrangements, including through Export Finance Australia, the Clean Energy Finance Corporation and Austrade's Export Market Development Grants program.
    - With support from Austrade, Indian customers to examine Australian offtake partnerships in light of Australia's extensive resource endowment, high sustainability and environmental standards and mature mining ecosystem that will support further productivity growth and competitiveness.

4. **Seek government and industry partnerships with third countries to support supply chain resilience**
    - Given gaps in the critical minerals supply chain in areas such as intermediate processing and component manufacturing, Australia and India to explore opportunities to partner with third countries that are active in the mid-stream phases of the supply chain.

- Australian and Indian governments to provide strategic direction and to consider policy initiatives that support cooperation through forums such as the Quad (Australia, India, US, Japan) and the Supply Chain Resilience Initiative (Australia, India, Japan).
- Austrade and partners to facilitate connections for Australian and Indian companies with industry stakeholders in markets such as Japan and Germany for dialogue on trilateral or multilateral commercial partnership arrangements.

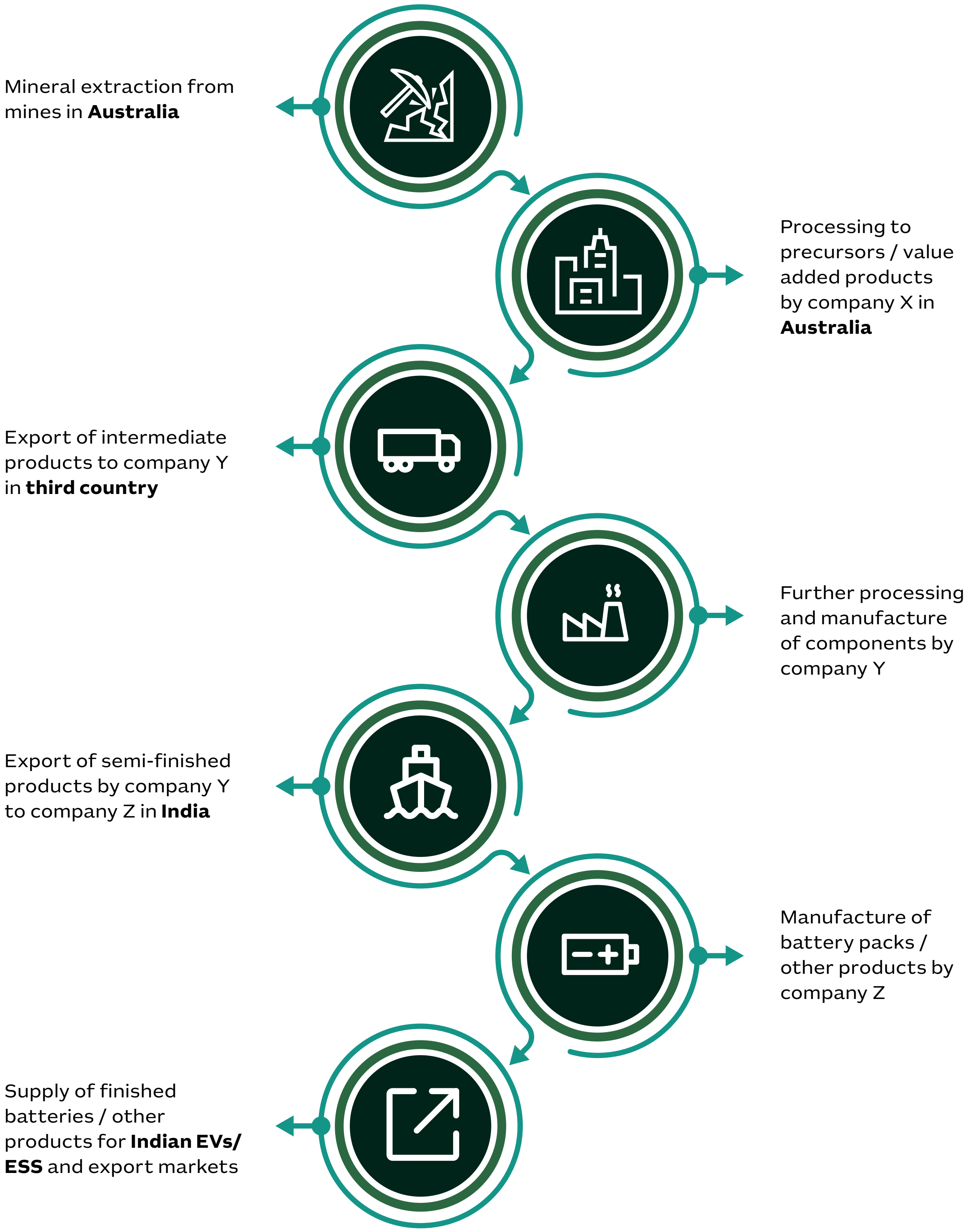
5. **Expand mining equipment, technology and services (METS) collaboration to drive productivity across the supply chain**

    - Austrade to identify India's critical mineral equipment, services and technology needs and facilitate introductions for Australian METS suppliers to Indian customers.
    - Australian public and private mining exploration organisations to pursue partnerships with Indian institutions for commercial and technical cooperation in expanding India's critical minerals exploration capability.
    - Australian mineral processing, digital mining transformation, mineral recycling and mining skills companies to seek targeted cooperation with Indian mining and downstream companies for provision of METS that will boost productivity in India's critical minerals sector.
    - Indian and Australian partners to examine opportunities to access India's production-linked incentive schemes or funding mechanisms such as the National Mineral Exploration Trust and National Clean Energy and Environment Fund (NCEEF) in order to fast-track project development.

6. **Develop a critical minerals community of practice for collaborative knowledge sharing, research and development**

    - Government, industry and research institutions in both markets to coordinate knowledge sharing and R&D, under the auspices of the JWG and with a clear, time-bound agenda for joint research.
    - The Australia-India Strategic Research Fund (AISRF) to offer funding for critical minerals cooperative projects, particularly those seeking to address supply chain and capability gaps in areas such as mineral processing.
    - Indian companies to consider becoming partners in the Future Batteries Industry Cooperative Research Centre (FBICRC), including to support joint research on intermediate processing and manufacturing capabilities in the battery supply chain.
    - Australian Government to form a coalition of partners for bilateral research that could include the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Geoscience Australia, the Australian Nuclear Science and Technology Organisation (ANSTO) and the Future Batteries Industry Cooperative Research Centre.
    - Indian Government to form a coalition of partners for bilateral research that could include the Clean Energy Research Initiative, the Automotive Research Association of India, technology institutes and the Council of Scientific and Industrial Research (CSIR) facilities.

Figure 4: Tripartite engagement model



Australia - India - Japan partnership potential[9]

The three nations launched the Supply Chain Resilience Initiative (SCRI) in 2020 to support resilient and sustainable supply chains. The global pandemic has exposed supply chain vulnerabilities. The SCRI aims to achieve balanced and inclusive growth in the region by sharing best practice on supply chain resilience and supporting trade diversification.

Japan is the fifth-largest investor in India and India imports a range of high-value manufactured products from Japan. These include electric machinery, electronics, steel, chemicals and heavy industrial equipment.

Japanese companies with major investments in India include Suzuki, Toyota, Honda, Nissan, Toshiba, DENSO, Mitsui, Mitsubishi, Marubeni, ITOCHU, Sumitomo Mitsui Banking Corporation, SONY, AGC Inc., RICOH, HITACHI, Mizuho Bank, and Panasonic.

The Australia-Japan economic relationship is underpinned by deep complementarity and Japan is Australia's second-largest trading partner. Japanese investments have been essential in the development of a range of export-oriented industries in Australia, including in the mining and energy sectors.

India offers market scale, a competitive manufacturing base, a highly skilled workforce and a strategic location. India's industrial growth agenda and ambitious plans for EVs and ESS will drive demand for critical minerals and related processing technologies. At present, India has limited declared domestic reserves for a majority of the identified critical minerals.

In a trilateral arrangement, raw and processed critical minerals could be exported from Australia to Japan. These could then be utilised in production of chemicals and components in Japan. These products would then be exported to India where they would become inputs for India's downstream industries.

The supply chain could further be bolstered by investment across the three markets. For example, Japanese trading majors could consider investment opportunities in Australian battery minerals projects, backed by Indian end-user companies. Similarly, Japanese chemical processing and automotive sector investment in India could provide potential channels to the Indian market for products moving through this supply chain.

This form of trilateral cooperation would draw on the close economic links between the three countries and would maximise each country's strengths within the supply chain.

Notes:

9. https://www.investindia.gov.in/country/japan-plus ; https://www.investindia.gov.in/country/australia ; https://www.dfat.gov.au/geo/japan/Pages/australia-japan-bilateral-relationship ; https://www.dfat.gov.au/geo/japan/Pages/australia-japan-bilateral-relationship#:~:text=Japan%20was%20Australia's%20second%2Dlargest%20trading%20partner%20in%202018%2D19,of%20our%20total%20goods%20exports ; https://www.tds-g.co.in/

Australia - India - Germany partnership potential[10]

India and Germany have shared a Strategic Partnership since 2001. They have extensive institutional links in areas such as defence, energy, smart cities, urban mobility and environmental management. There are more than 150 Indo-German science and technology joint research projects and 70 direct partnerships between universities of both the countries.

Germany is India's largest trading partner in Europe and the seventh-largest foreign investor in India, with more than 1,700 German companies active in India and over 600 Indo-German joint ventures. German investments in India focus on sectors such as transportation, electrical equipment, metallurgical industries, chemicals, construction and automotive.

Germany has a strong technical base for processes and components of the lithium-ion battery value chain. This includes chemical majors such as BASF, a number of battery and component manufacturers, and specialised research institutions.

Australia and India could consider opportunities to partner with Germany for supply chain integration. Indian end users could source processed minerals from Australian mining companies, with the minerals refined and transformed in Germany before being sent on to India for further value addition and assembly.

By way of example, EcoGraf Limited is an Australian company establishing a vertically integrated 20,000 tonnes per annum processing plant in Kwinana, Western Australia, to produce SPG. The project will utilise a new environmentally sustainable process to offer battery anode material to the lithium-ion battery industry.

EcoGraf have a long-term agreement with German graphite trading group Technografit GmbH for sourcing and supplying natural flake graphite to the Kwinana facility. Following initial scoping and feasibility studies by GR Engineering Consultants Australia and CSIRO Australia, four years of pilot plant test work was undertaken in Germany. This allowed EcoGraf to confirm and optimise their processing capabilities.

Given India's clean energy agenda, there is a potential market in India for companies such as EcoGraf both for supply of graphite products as well as for establishment in India of recycling and processing facilities.

Given each country's strengths in mining and downstream industry-related research and development, this form of trilateral partnership could also include multi-party R&D collaboration to maximise efficiencies and productivity across the supply chain.

Notes:

10. https://www.investindia.gov.in/country/germany ; https://www.dfat.gov.au/geo/germany/germany-country-brief#:~:text=Economic%20diplomacy,mostly%20goods%20(%2413.7%20billion ; https://www.industry.gov.au/data-and-publications/resources-technology-and-critical-minerals-processing-national-manufacturing-priority-road-map ; https://www.dfat.gov.au/geo/germany/germany-country-brief#:~:text=Australia's%20economic%20relationship%20with%20Germany,mostly%20goods%20(%2413.7%20billion) ; https://www.ecograf.com.au/business/ecograf/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CRITICAL MINERALS SUPPLY SCENARIO IN INDIA

India produces 95 minerals, including four fuel, 10 metallic, 23 non-metallic, three atomic, and 55 minor minerals. Globally, India is amongst the top five producers of bulk minerals, such as coal, bauxite, iron ore, chromite, and zinc.[11]

However, India largely relies on imports for the supply of many critical minerals, such as cobalt, lithium, germanium, rhenium, beryllium, niobium, tantalum, vanadium, strontium, nickel, and rare earths.

This is due both to limited availability of reserves of the mineral forms in India as well as a lack of systematic mineral exploration processes.

Table 1: Snapshot of critical minerals in India[12]

Category	Mineral	India's production in 2020 (metric tonnes)	India's reserves (metric tonnes)	India's resources (metric tonnes)	India's rank (for reserves)	Country with largest reserves
Battery minerals	Lithium	-	-	-	-	Chile
Battery minerals	Cobalt	-	-	44,910,000[13]	-	Democratic Republic of Congo (DRC)
Battery minerals	Nickel	-	-	189,000,000[14]	-	Indonesia
Battery minerals	Graphite	34,000	8,000,000	194,886,779[15]	7th	Turkey
Battery minerals	Manganese (in terms of manganese content)	640,000	34,000,000	495,874,000[16]	7th	South Africa
Titanium- bearing minerals	Ilmenite[17] (in metric tonnes of contained titanium dioxide)	160,000	85,000,000	629,570,000[18]	3rd	China
Titanium- bearing minerals	Rutile[19] (in metric tonnes of contained TiO_2)	11,000	7,400,000	33,950,000[20]	2nd	Australia
Rare earths	Light and heavy rare earths (in metric tonnes of rare earth oxide equivalent)	3,000	6,900,000	-	5th	China
Alloying elements	Vanadium	442[21]	-	24,633,855[22]	-	China

Notes:

11. Source: Report of Sub-Group II on metals and minerals- strategy based upon the demand and supply for mineral sector of the Working Group on mineral exploration and development for the 12th five-year plan published by Government of India, Planning Commission; Indian Minerals Yearbook 2019;
12. https://pubs.er.usgs.gov/publication/mcs2021
13. https://ibm.gov.in/writereaddata/files/09022020154028Cobalt_2019.pdf
14. https://ibm.gov.in/writereaddata/files/06232020150332Nickel_2019.pdf
15. https://ibm.gov.in/writereaddata/files/07072020143852Graphite_2019.pdf
16. https://ibm.gov.in/writereaddata/files/01072021154458Manganeseore_2019.pdf, resource of manganese ore and not by manganese content
17. Reserves are mentioned in metric tonnes of contained Titanium Dioxide (TiO2)
18. https://ibm.gov.in/writereaddata/files/10012020172127Ilmenite_2019_AR.pdf, in situ resource for ilmenite
19. Reserves are mentioned in metric tonnes of contained TiO2
20. https://ibm.gov.in/writereaddata/files/10012020172127Ilmenite_2019_AR.pdf, in situ resource for rutile
21. By-product from slag during alumina production during 2018-19, https://ibm.gov.in/writereaddata/files/06052020113429Vanadium_2019.pdf
22. https://ibm.gov.in/writereaddata/files/06052020113429Vanadium_2019.pdf

Category	Mineral	India's production in 2020 (metric tonnes)	India's reserves (metric tonnes)	India's resources (metric tonnes)	India's rank (for reserves)	Country with largest reserves
Alloying elements	Niobium	-	-	-	-	Brazil
Alloying elements	Chromium (in the form of chromite ore)	4,000,000[23]	100,000,000	344,016,000[24]	3rd	Kazakhstan
Alloying elements	Silicon (as silica in various natural forms, such as quartzite)	55,000[25]	Abundant	Abundant	-	China[26]
Others	Germanium	-	-	-	-	China[27]
Others	Rhenium	-	-	-	-	Chile
Others	Beryllium	-	-	-	-	United States
Others	Tantalum	-	-	-	-	Australia
Others	Strontium	-	-	-	-	Spain[28]
Others	Zirconium (as zircon)	11,906[29]	-	33,710,000[30]	-	Australia

Figure 5: Net import reliance for critical minerals in India, 2020

Critical mineral	Percentage (2020)	Major import sources (2020)
Lithium	100	Chile, Russia, China, Ireland, Belgium
Cobalt	100	China, Belgium, Netherlands, US, Japan
Nickel	100	Sweden, China, Indonesia, Japan, Philippines
Vanadium	100	Kuwait, Germany, South Africa, Brazil, Thailand
Niobium	100	Brazil, Australia, Canada, South Africa, Indonesia
Germanium	100	China, South Africa, Australia, France, US
Rhenium	100	Russia, UK, Netherlands, South Africa, China
Beryllium	100	Russia, UK, Netherlands, South Africa, China
Tantalum	100	Australia, Indonesia, South Africa, Malaysia, US
Strontium	100	China, US, Russia, Estonia, Slovenia
Zirconium (zircon)	80	Australia, Indonesia, South Africa, Malaysia, US
Graphite (natural)	60	China, Madagascar, Mozambique, Vietnam, Tanzania
Manganese	50	South Africa, Gabon, Australia, Brazil, China
Chromium	2.5	South Africa, Mozambique, Oman, Switzerland, Turkey
Silicon	<1	China, Malaysia, Norway, Bhutan, Netherlands

The end-use industry in India for rare-earth (e.g. permanent magnets) and titanium bearing minerals ilmenite and rutile (e.g. titanium metal/alloys) are largely dependent on imports from other countries.

Notes:
23. High carbon and low carbon ferrochromium combined
24. Reserves are shipping-grade chromite ore, which is deposit quantity and grade normalised to 45% Cr2O3
25. Silicon content of ferrosilicon only
26. Country with highest production
27. Country with highest production
28. Country with highest production
29. As reported by IREL (India) Limited in 2018-19, https://ibm.gov.in/writereaddata/files/09102020171409Zircon_2019.pdf
30. Department of Atomic Energy, Mumbai, https://ibm.gov.in/writereaddata/files/09102020171409Zircon_2019.pdf

Supply challenges for critical minerals in India

India is entirely dependent on imports for lithium, cobalt, nickel, vanadium, niobium, germanium, rhenium, beryllium, tantalum, and strontium. It does not have declared reserves or resources of these minerals.

India has modest reserves of cobalt, nickel, and vanadium. Small amounts of these minerals are available through recovery processes. India had no reported reserves of lithium until in 2020, one very small lithium reserve was discovered.

India has an estimated 44.91 million tonnes (Mt) of cobalt, with about 69 percent in Odisha, according to the National Mineral Inventory published by the Indian Bureau of Mines (IBM). The remaining resources are in Jharkhand and Nagaland.[31]

At present, India does not commercially produce cobalt from primary resources. The country's existing capabilities do not support cost-effective extraction of cobalt. India's cobalt refining capacity is estimated at 2,060 tonnes per year.[32]

India has an estimated 189 Mt of nickel, according to the National Mineral Inventory. Nickel occurs principally as oxides, sulphides, and silicates. India has a source of nickeliferous limonite in the overburden of chromite in the Sukinda Valley in Jajpur, Odisha.

Nickel has also been found in uranium deposits at Jaduguda, Jharkhand, and a process is being developed for its recovery. Resources are spread across the Singhbhum East district of Jharkhand and Jajpur, and the Keonjhar and Mayurbhanj districts of Odisha.

To date, the high cost of detailed exploration and extraction of nickel has made commercial production challenging in India.[33]

India has an estimated 24.6 Mt of vanadium, with about 64,594 tonnes of vanadium pentoxide (V_2O_5), according to the National Mineral Inventory.[34]

Vanadium resources are available in Karnataka, Maharashtra, and Odisha. High exploration and extraction cost has hindered commercial production of vanadium in India. Reported production of vanadium as a by-product of slag in alumina refineries was about 442 tonnes in 2018–19.[35]

India is heavily dependent on imports of graphite, despite having large deposits. It has an estimated 194.89 Mt of graphite (7.96 Mt of this is reserves), according to the National Mineral Inventory. About 4 percent of India's total graphite resources have been translated into economically viable reserves.[36]

Graphite reserves are available in Jharkhand, Tamil Nadu, Odisha, and Chhattisgarh. Arunachal Pradesh and Jammu & Kashmir account for about 70 percent of the total resources.

The bulk of the graphite resources are unexplored and those that have been identified are of poor grade – only 2.91 Mt of resources contain more than 40 percent fixed carbon. India can lower its import dependency by exploring and opening new mines in the near future.[37]

India has an estimated 495.87 Mt of manganese (93.47 Mt is reserves), according to the National Mineral Inventory. Most of the manganese ore is available in Odisha, Karnataka, Maharashtra, and Madhya Pradesh, which is the leading producer of manganese in India.

Manganese ore's quality varies amongst deposits, with about 46 percent that is medium-grade and blast-furnace grade ferromanganese.[38] Current production in key mines contains high proportions of medium- and low-grade ores. This has led downstream industries to pursue offtake import agreements with manganese ore producers internationally.[39]

Notes:

31. ttps://ibm.gov.in/writereaddata/files/09022020154028Cobalt_2019.pdf
32. https://ibm.gov.in/writereaddata/files/09022020154028Cobalt_2019.pdf
33. https://ibm.gov.in/writereaddata/files/06232020150332Nickel_2019.pdf
34. https://ibm.gov.in/writereaddata/files/06052020113429Vanadium_2019.pdf
35. https://ibm.gov.in/writereaddata/files/06052020113429Vanadium_2019.pdf
36. https://ibm.gov.in/writereaddata/files/07072020143852Graphite_2019.pdf
37. https://ibm.gov.in/writereaddata/files/07072020143852Graphite_2019.pdf
38. https://ibm.gov.in/writereaddata/files/01072021154458Manganeseore_2019.pdf
39. https://moil.nic.in/userfiles/Annual%20Report%202019-20.pdf

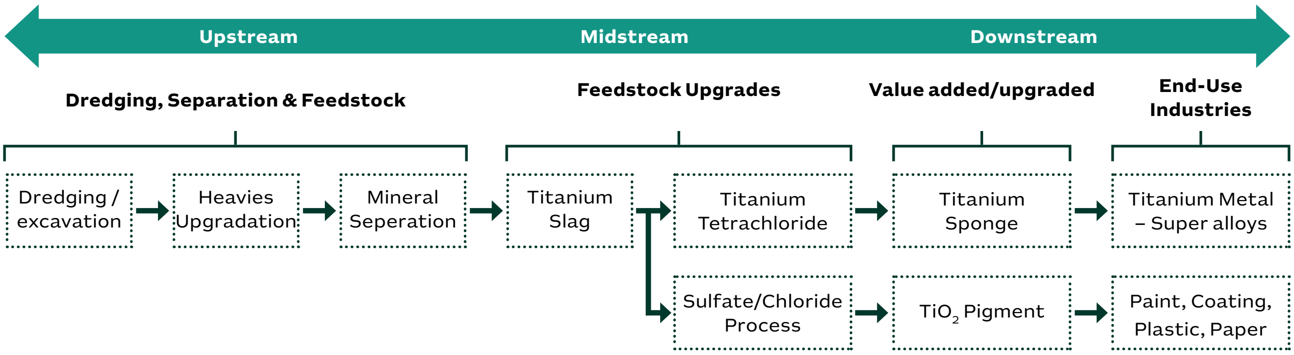
Despite having the world's third-largest deposits of titanium-bearing minerals and fifth-largest deposits of rare earths, India depends on imports because it lacks suitable commercial scale technologies for value addition.

India lacks the downstream value chain for titanium metal or alloy due to the unavailability of commercial-scale technologies to produce titanium sponge.

Globally, six companies are extracting titanium sponge and slag through proprietary technologies. These companies include VSMPO-AVISMA in Russia, Ust-Kamenogorsk Titanium and Magnesium Plant Joint Stock Company (UKTMP JSC) in Kazakhstan, and Toho Titanium in Japan.

IREL (India) Limited, the leading producer of titanium-bearing minerals in India, signed a MOU with UKTMP JSC to produce titanium slag in India.[40]

Figure 6: Titanium value chain in India

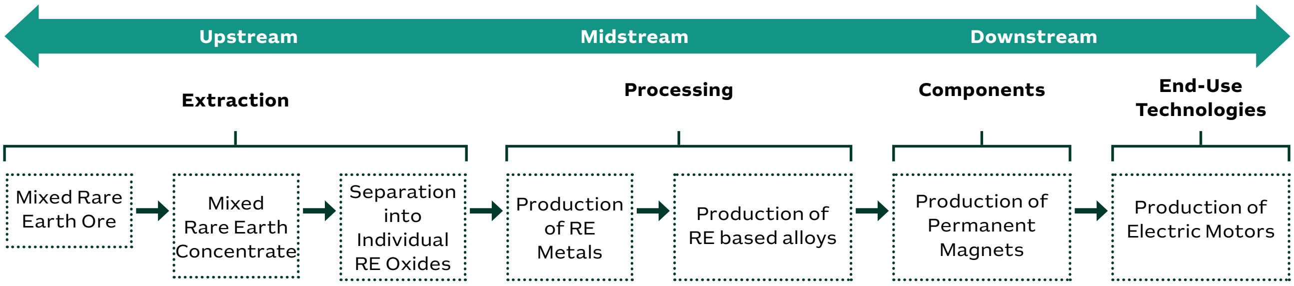


India exports upstream products in the form of rare earth oxides and imports rare earths containing intermediate products required for various applications or finished products, such as rare earth magnets.

The technology for converting rare earth oxides into metal or alloy is proprietary, and closely held by a small number of countries. Commercial-scale technologies for producing titanium slag, sponge, and metal are not available in India.

Technology transfer will enable India's domestic titanium and rare earth supply.

Figure 7: Rare earth value chain in India[41]



Notes:

40. https://psuwatch.com/irel-signs-mou-with-uktmp-jsc-kazakhstan-for-production-of-titanium-slag
41. Industry analysis

India's rare earth value chain is not well developed, with limited commercial scale production in the midstream and downstream sectors in India.

While India has significant resource potential in critical minerals, including cobalt, nickel, graphite, vanadium and manganese, import dependency in these minerals is in part due to limited spending on exploration and the non-availability of exploration technologies.

Mineral exploration in India is valued at US$100 million (A$145 million) annually, which is considerably less than other mineral-rich geographies, such as Australia and Canada.[42]

India's mineral exploration is primarily carried out by the public sector, although recent reforms are providing private sector operators limited opportunities to undertake mineral exploration.

Deep-seated minerals exploration has been limited in India because of technology gaps for exploring mineralised zones. Private sector participation has been limited to sub-contractors performing drilling and associated works for government exploration agencies.

Mineral-rich geographies, such as Australia, Canada, and the United States, have robust ecosystems for junior mining companies. In Australia, tax incentives are provided through the Junior Minerals Exploration Incentive to encourage investment in exploration.

India could explore similar mechanisms to encourage private exploration, especially for critical minerals.

Strategic cooperation for critical minerals supply

Global capacity for extraction and processing of critical minerals is concentrated in a small number of markets.

This creates vulnerability in critical minerals supply chains, including for supplying minerals and processing, refining and manufacturing metals, chemicals and intermediates for lithium-ion batteries, cell chemistry, permanent magnets and special alloys.

This has paved the way for international collaboration to build integrated mining and mineral processing supply chains.

For example, the Supply Chain Resilience Initiative between Australia, India, and Japan can support development of a reliable supply chain for critical minerals involving these countries.[43]

Australia has abundant reserves of critical minerals, including the world's largest concentration of battery minerals. Australian battery mineral resources include lithium, cobalt, nickel, and manganese reserves.

Australia is also a leading supplier of titanium bearing minerals (ilmenite, rutile, and leucoxene), rare earths, niobium, tantalum, zirconium, and vanadium, amongst others.

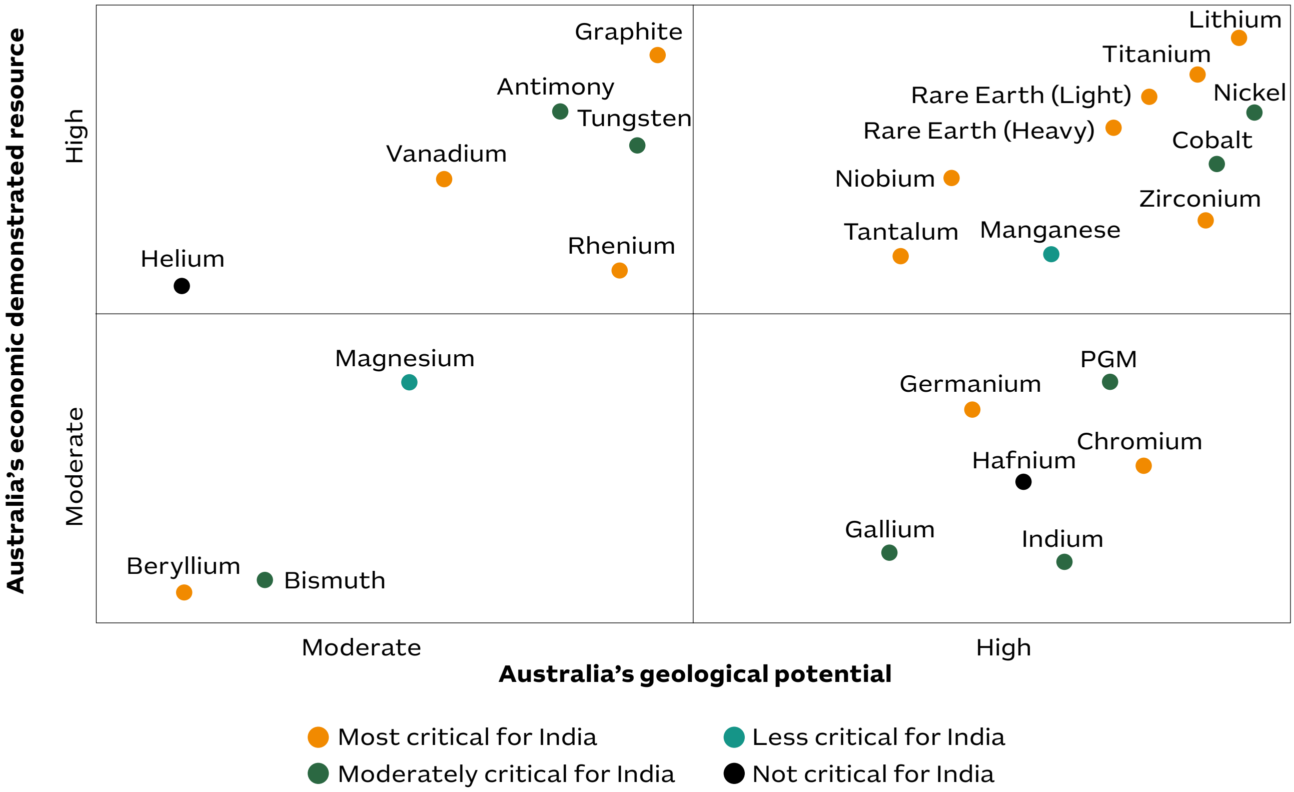
The Australian Government published its *Critical Minerals Strategy* in 2019 and the *Australian Critical Minerals Prospectus 2020*, with a focus on financing and supporting projects to extract and process critical mineral supplies.

A comparison across Australia and India shows that both the markets have a focus on lithium, cobalt, rare earths, vanadium, titanium, nickel, and graphite.

Notes:

42. https://www.brookings.edu/research/indias-mineral-exploration-legacy/
43. https://economictimes.indiatimes.com/news/economy/foreign-trade/india-japan-australia-decide-to-launch-resilient-supply-chain-initiative-in-the-indo-pacific-region/articleshow/77870346.cms?from=mdr

Figure 8: Australian geological potential for critical minerals[44]



Prioritising critical minerals in focus categories

We have shortlisted priority critical minerals for bilateral cooperation based on India's demand and import dependency, as well as Australia's reserves and capability to supply.

Battery minerals

In India, electric mobility and grid storage requirements will drive growth for battery storage capacity and an increase in battery manufacturing over the next decade. The primary minerals used in lithium-ion batteries are cobalt, lithium, manganese, nickel, and graphite.

Amongst these, India has considerable reserves and/or resources of manganese. For that reason, this report includes a deep dive into four battery minerals – lithium, cobalt, nickel, and graphite.

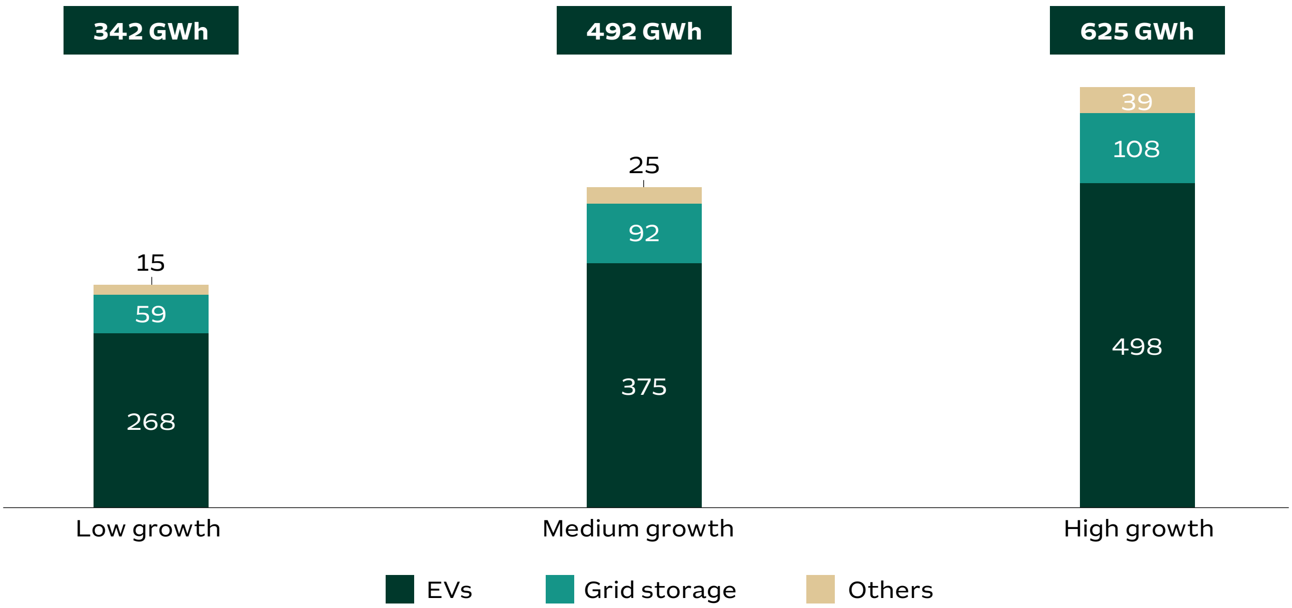
India's lithium-ion battery market is expected to grow to about 492 GWh by 2030.[45] Under this scenario, grid-scale storage and EVs will account for 98 percent of the overall storage requirements.

Notes:

44. Australia's Critical Minerals Strategy 2019 by Australia Trade and Investment Commission; Australian Critical Minerals Prospectus 2020; Critical non-fuel mineral resources for India's manufacturing sector – A vision for 2030 by Department of Science & Technology, India & CEEW, 2016; PGM implies Platinum Group Metals

45. Total EV sales 2020-2030: 2W: 65 Mn, 3W: 3.9 Mn, 4W passenger: 4.3 Mn, 4W commercial: 0.53 Mn, Buses: 84,000; Battery size: 2W: 2kWh, 3W: 6kWh, 4W passenger: 40kWh, 4W commercial: 60kWh, Buses: 200kWh; Grid scale storage – As estimated by Central Electricity Authority for optimal generation mix 2029-30 (Scenario I); storage size in "others" category is calculated assuming a minimum 20% battery penetration; 80% depth of discharge is assumed to calculate battery size. This estimate does not include demand from consumer electronics, UPS and data centres

Figure 9: Total battery demand in India by 2030



Notes:
'Others' includes demand from solar pumps and the micro grid, railways, telecommunications, diesel generating set replacement and captive power plants

Titanium-bearing minerals and rare earths

India's mainland coastline is more than 7,500 km long. Beach sand deposits contain heavy minerals, including titanium-bearing minerals and rare earths across large part of the coastline.

However, India imports the majority of its midstream and downstream value-added products in the titanium and rare earth value chains due to lack of local technology or transfer of commercial-scale proven technology.

Critical minerals with alloy and steel applications

These minerals include nickel, graphite, chromium, vanadium, manganese, silicon, and niobium, with applications in steel and alloys. Nickel and graphite are essential due to their applications in battery storage in addition to alloy and steel applications.

Vanadium is important due to India's total import dependence and vanadium's likely future applications in battery storage.

India has widespread deposits of chromium and silicon, and limited import dependency; niobium consumption in India is minimal. Accordingly, these minerals were not included in the deep dive sections that follow.

Other minerals

Minerals such as germanium, rhenium, beryllium, strontium, zirconium, and tantalum were not considered for deep dive due to limited consumption in India, notwithstanding that the country does rely on import for these minerals.

DEEP DIVE FOR PRIORITISED CRITICAL MINERALS

Lithium

As the primary ingredient in lithium-ion batteries, lithium will become increasingly important as demand for EVs increases.

Apart from lithium-ion batteries, lithium is used in glass, ceramics, heat-resistant greases, lubricants, lightweight aircraft materials, pharmaceuticals, and dental implants.

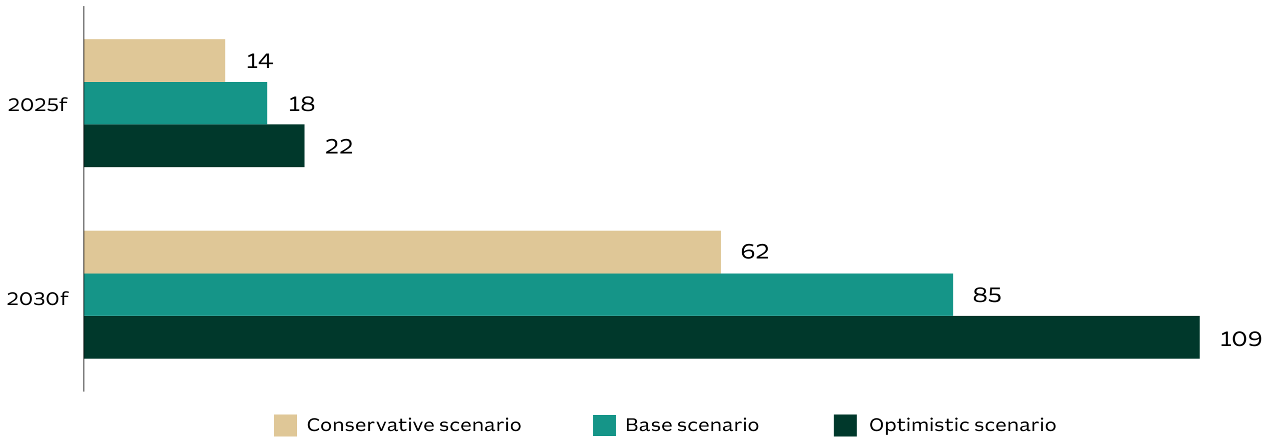
India's lithium-ion battery manufacturing ecosystem is emerging. Manufacturers may invest in establishing lithium refining, cell manufacturing and battery assembly units in India.

Australia has large lithium spodumene reserves that could help meet increasing Indian demand for lithium.

Indian market analysis

The India market used an estimated 0.8-1 kilo tonnes (kt) of lithium in 2020 and is expected to reach a cumulative demand potential of 62-109 kt by 2030.[46]

Figure 10: Cumulative Indian lithium market demand potential (kt) [47]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	22	18	14	109	85	62

Disclaimer: The demand potential identified shall be subject to the expected development of lithium-ion battery value chain in India.

Notes:

46. Analysis based on publicly available information in the following government and other reports – NITI Aayog: India's Electric Mobility Transformation: Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; CRISIL: by 2024, nearly half of new three-wheelers sold will be e-autos; Avendus, July 2020: Electric vehicles: Charging towards a bright future; and ICRA press release 2020. While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.

47. Analysis based on publicly available information in the following government and other reports – NITI Aayog: India's Electric Mobility Transformation: Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; CRISIL: by 2024, nearly half of new three-wheelers sold will be e-autos; Avendus, July 2020: Electric vehicles: Charging towards a bright future; and ICRA press release 2020. While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.

Lithium demand is primarily driven by lithium-ion batteries, which are typically used in applications such as EVs, mobile phones, laptops, power backup appliances, and other electrical goods.

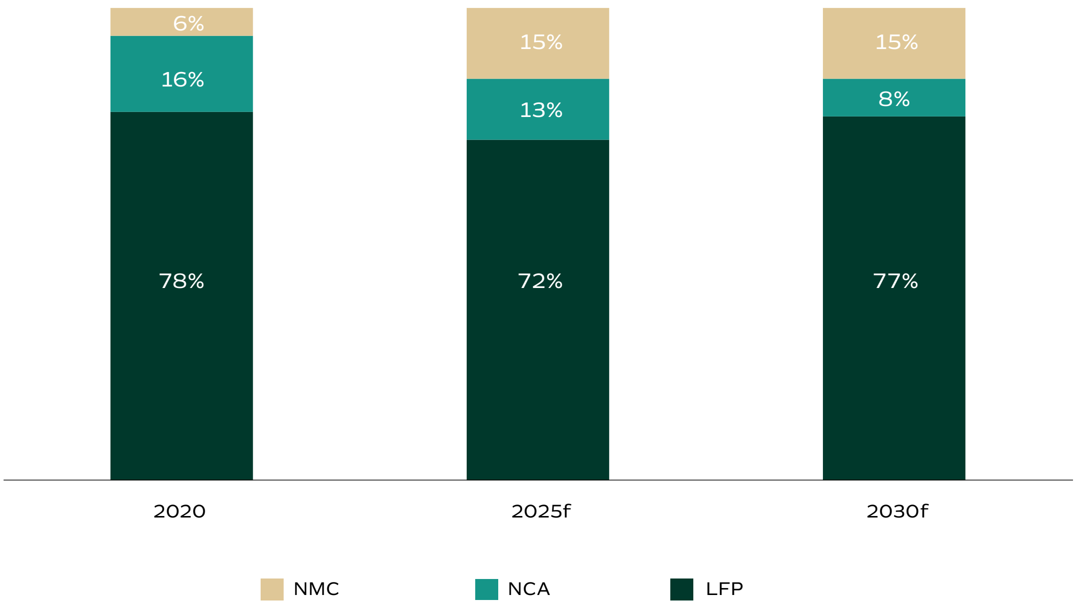
Table 2: Indian lithium market forecast by volume of end-use segment[48]

End-use segment	2020e	2025f	2030f
Electric vehicles	71%	70%	70%
Other batteries	14%	20%	21%
Other non-battery uses (including ceramics, lubricants, pharmaceuticals, and research)	15%	10%	9%

The three dominant lithium-ion cathode chemistries used for manufacturing lithium-ion batteries are Lithium Iron Phosphate (LFP), Lithium Nickel Manganese Cobalt (NMC) oxide, and Lithium Nickel Cobalt Aluminium (NCA) oxide.

Depending on battery chemistries and configurations, lithium content is usually 5–6 percent of cathode weight in NMC and 6–7 percent in NCA.[49] Lithium is either consumed as lithium carbonate produced from brine or lithium hydroxide primarily produced from pegmatite.

Figure 11: Lithium-ion battery chemistry trends[50]



Notes:

48. Analysis based on publicly available information in the following government and other reports - NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new three-wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020. India is expected to replicate the global application trends. Other batteries include demand from solar pumps and micro grid and railway – traction, telecom, DG replacement, and captive power plants
49. Syrah sources
50. Bloomberg New Energy Finance, The Ultimate Guide to the Cobalt Market: 2021–2030 (crux investor)

Key industry participants

Key Indian consumers of lithium would be manufacturers of active cell chemicals (ACC) and battery cells. While lithium has other pharmaceutical and manufacturing uses, about 90 percent of lithium demand will be from Indian lithium-ion battery sector.[51]

Due to lack of a lithium-processing ecosystem, India currently imports a significant share of its lithium-ion batteries and battery materials.

Indian battery manufacturers are seeking to develop a lithium battery ecosystem to fulfil anticipated demand from the EV sector. These manufacturers include:

- Tata Chemicals Limited: Has a plant in Dholera, Gujarat, and plans to manufacture up to 10 GWh per year of lithium ion battery components[52]
- TDS Lithium-Ion Battery Gujarat Private Limited (TDSG): A JV between Toshiba Corporation, DENSO Corporation, and Suzuki Motor Corporation, set up a plant to produce 1 GWh batteries for Suzuki Motor's plant in Gujarat[53]
- Exide Industries: Formed a JV with Swiss firm Leclanché to build an assembly line to supply 1.5 GWh of lithium-ion batteries and ESS[54]
- Manikaran Power Limited and Neometals Limited: Conducting a feasibility study for a lithium refinery in India, with a nominal capacity of 20,000 Mt of lithium carbonate equivalent (lithium hydroxide)[55]
- Amara Raja: Announced in 2021 the opening of a technology hub to develop lithium-ion cells in Tirupati, Andhra Pradesh[56]
- Reliance Industries: Has announced a plan for four large-scale production bases to manufacture all components of their new energy ecosystem, including batteries for energy storage[57]

Table 3: Indian developments in the lithium ecosystem - summary[58]

Activities	Developments
Exploring domestic and international resources for lithium	• 2020: India's first lithium reserve of 1.6 kt is discovered in Karnataka • 2020: Khanij Bidesh India Limited (KABIL) begins exploration of 17 Mt of lithium in South America (KABIL was formed in 2019)
Lithium processing and refining	• 2020: Manikaran Power Limited and Neometals Limited launches a feasibility study for setting up a lithium refinery in India, with a nominal capacity of 20 kt of lithium carbonate equivalent (lithium hydroxide)
Component manufacturing	• 2020: TATA Chemicals plans to manufacture up to 10 GWh per year of lithium-ion battery components. Its plant will also have recycling operations
Battery manufacturing and/or assembly	• 2017: TDSG JV forms to manufacture and supply lithium-ion batteries to the Suzuki Motor Plant in Gujarat • 2018: Exide Industries forms a JV with Swiss firm Leclanché to build an assembly line to supply 1.5 GWh of lithium-ion batteries and ESS • 2020: Japanese firm Amperex Technology Limited buys land in Haryana, India, to set up a lithium-ion polymer battery manufacturing unit • 2021: Amara Raja announces it is opening a technology hub to develop lithium-ion cells in Tirupati

Notes:

51. Secondary research and Industry sources
52. https://www.tatachemicals.com/Asia/Products/Specialty-chemistry/Energy-Sciences/energy-storage-solutions
53. https://www.tds-g.co.in/
54. https://nexcharge.in/
55. https://www.manikaranpowerltd.in/upload/MPL-Lithium-Press-Release.pdf
56. https://www.business-standard.com/article/companies/amara-raja-starts-work-on-lithium-ion-cells-sets-up-tech-hub-at-tirupati-121022100451_1.html
57. https://www.ril.com/ar2020-21/pdf/RIL-Integrated-Annual-Report-2020-21.pdf
58. Company annual reports and industry discussions

Lithium reserves

Lithium is produced from hard rocks (pegmatite), brines, or clay-based sedimentary deposits. In 2019, world economic resources of lithium were 19,500 kilo tonnes of lithium metal. In 2020, world lithium reserves were estimated at 21 million tonnes.[59]

Expanded global exploration has identified global lithium resources of 86 million tonnes.[60] In 2019, Australia had Economic Demonstrated Resources (EDR) of 5,702 kilo tonnes (kt) lithium. Australia produced 45,000 tonnes of lithium in 2019 and 40,000 tonnes in 2020.

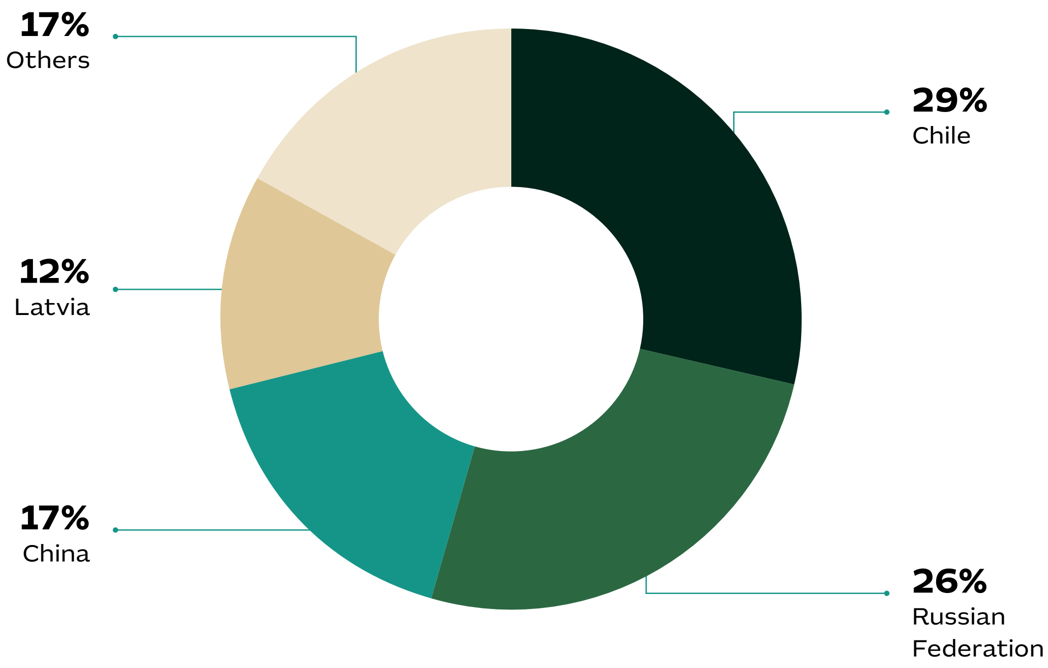
At present, eight countries produce lithium, with Chile, Australia, and Argentina accounting for 85 percent of the global production.[61] Chile, Bolivia, and Argentina produce lithium from brine, while Australia produces lithium from hard rock. In China, lithium is produced from both the sources.

Indian supply landscape

In 2020, India discovered its first lithium pegmatites reserve consisting of 1.6 kt in the Marlagalla-Allapatna region of Karnataka's Mandya district.[62]

India currently imports 100 percent of its lithium in various industrial forms, including lithium oxide (about 1 kt), lithium hydroxide (about 1 kt), and lithium carbonate (nearly 1 kt). Lithium cells and battery packs are also imported for smaller electronics products and mobile phones. Lithium is primarily imported as lithium-ion batteries (about 16 kt) for EVs and ESS.[63]

Figure 12: Import of lithium oxide and hydroxide in 2020[64]



Notes:

59. USGS – Lithium Mineral commodities summary, https://pubs.er.usgs.gov/publication/mcs2021, excludes the United States of America
60. _https://pubs.er.usgs.gov/publication/mcs2021
61. McKinsey Report: Lithium and cobalt: A tale of two commodities
62. https://pib.gov.in/PressReleasePage.aspx?PRID=1694796
63. UN Comtrade, https://comtrade.un.org/
64. UN Comtrade, https://comtrade.un.org/

Figure 13: Imports of lithium carbonate in 2020[65]

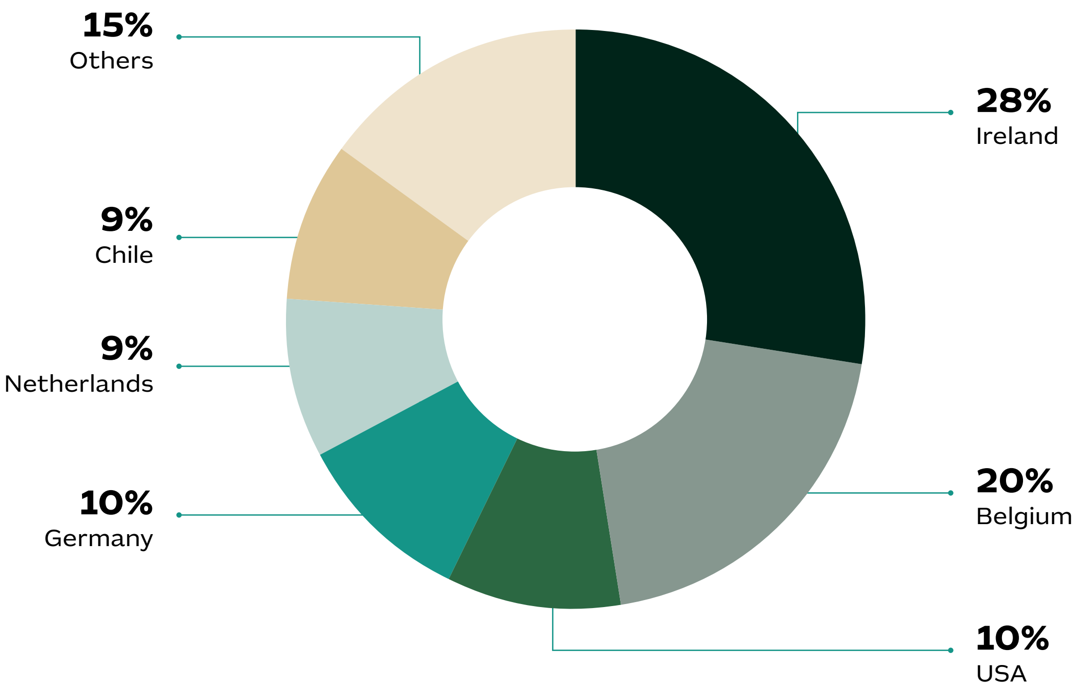


Table 4: Indian imports of lithium and lithium concentrates[66]

Import product description	HS code	2019		2020	
		Volume (kt)	Value (A$ million)	Volume (kt)	Value (A$ million)
Lithium oxide and hydroxide	282520	1.9	33	1.9	18
Lithium carbonate	283691	1.3	18	1	12
Primary lithium for cell batteries	850650	0.1	30	0.4	32
Raw material and/or inputs for manufacturing battery cells	850760	22.7	1,295	16.22	1,536

Most of the lithium oxide and hydroxide imported into India is from Chile, Russia, China, and Latvia.[67] In 2020, India's major sources of lithium carbonate were Ireland, Belgium, the United States, and Germany.[68]

Notes:
65. UN Comtrade, https://comtrade.un.org/
66. UN Comtrade, https://comtrade.un.org/
67. UNCOMTRADE HS Code 282520
68. UNCOMTRADE HS CODE 283691

The Indian Government has recently imposed import duties on lithium products to promote local manufacturing of batteries. The following table lists Basic Customs Duty (BCD) the government has imposed on imported lithium products.

Table 5: Import duties on lithium-ion batteries in India from April 2021[69]

	HS code	Basic Customs Duty (BCD)	Social Welfare Surcharge (SWS)	Integrated Goods and Services Tax (IGST)	Total duty
Lithium oxide and hydroxide	2825	10%	10%	18%	29.8%
Lithium carbonate	2836	10%	10%	18%	29.8%
Cells and battery packs	8506	10%	10%	28%	40.8%
Lithium-ion cells for accumulator in EVs	8507	10%	10%	28%	40.8%

Note: The IGST is applicable on both imports and Indian manufacture and is an eligible 'input tax credit', which can be offset against GST liability.

Lack of a commercial value chain and limited lithium reserves in India gives Australian manufacturers an opportunity to supply lithium hydroxide or lithium carbonate to India.

As many Indian companies in the lithium battery industry or value chain are large conglomerates, Australian asset owners can seek investments in mining, upstream projects, and other partnership alliances, such as R&D.

Australian supply capability

Australia extracts spodumene comprising 58 percent lithium oxide. Spodumene undergoes chemical processing to form lithium carbonate and lithium hydroxide for industrial applications.

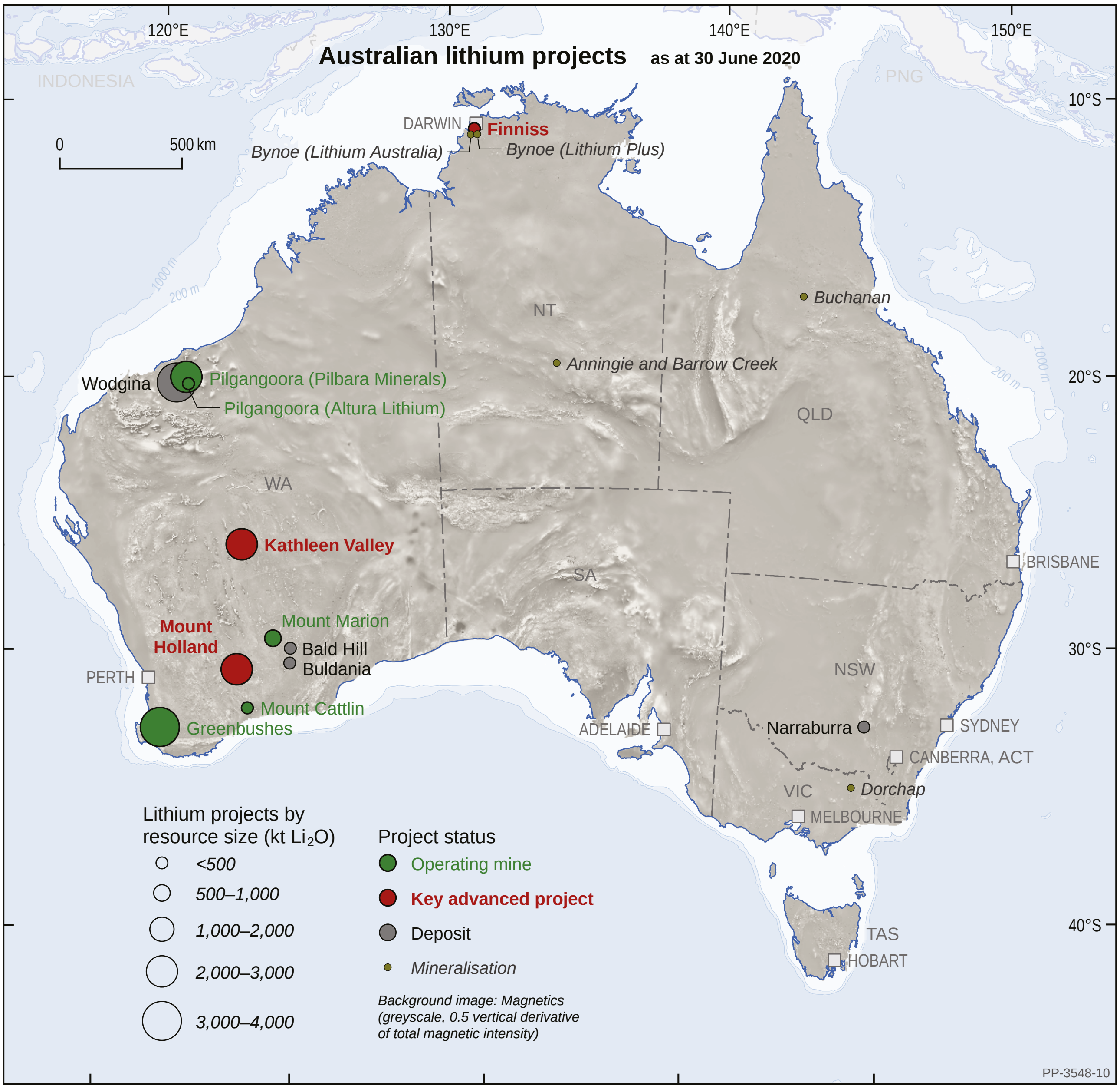
With 56 percent of the global lithium production, Australia was ranked as the top lithium producer in 2019.[70] In that year, Australia's Economic Demonstrated Resources (EDR) of lithium metal was 5,702 kilo tonnes, ranking it second globally after Chile, with 29 percent of the world's EDR.

Over 84 percent of Australia's lithium EDR is held in four deposits: Greenbushes (Tianqi Lithium Australia Pty Ltd), Wodgina (Mineral Resources Ltd), Pilgangoora (Pilbara Minerals Ltd), and Earl Grey (Mount Holland Lithium Project; jointly owned by Wesfarmers Ltd and Sociedad Quimica y Minera de Chile). Western Australia has significant reserves and accounts for nearly 98 percent of Australia's lithium production, with 0.5 percent in the Northern Territory.[71]

Notes:

69. CBIC -Ministry of Commerce
70. Australian Critical Minerals Prospectus 2020
71. Australian Critical Minerals Prospectus 2020

Figure 14: Australian lithium projects



Source: Australian Critical Minerals Prospectus 2020

The following table focuses on Australia's operating mines and a robust project pipeline to meet future lithium requirements.

Table 6: Australia's upcoming lithium projects

Critical mineral	Project name	Company	Project status	Primary mineral(s)	Tonnage (Mt)	Grade	Units		Contained (kt)
Lithium	**Greenbushes**	Talison Lithium Au Pty Ltd	Operating	Li	157.1	2.25	%	Li_2O	3,532
Lithium	**Pilgangoora (Pilbara Min)**	Pilbara Minerals Ltd	Operating	Li, Ta	223.2	1.27	%	Li_2O	2,835
Lithium	**Mt Marion**	ASX:MIN; Gangfeng Lithium	Operating	Li	72.9	1.37	%	Li_2O	995
Lithium	**Pilgangoora (Altura)**	Altura Mining Ltd	Operating	Li	45.7	1.06	%	Li_2O	482
Lithium	**Mt Cattlin**	Galaxy Resources Ltd	Operating	Li, Ta	14.6	1.29	%	Li_2O	188
Lithium	**Wodgina**	Mineral Resources Ltd	Care and maint	Li, Ta	259.2	1.17	%	Li_2O	3,032
Lithium	**Mount Holland**	Wesfarmers Ltd; SQM	FS	Li	189.0	1.50	%	Li_2O	2,843
Lithium	**Bald Hill**	Alita Resources Ltd	Care and maint	Li, Ta	26.5	0.96	%	Li_2O	255
Lithium	**Finniss**	Core Lithium Ltd	FS	Li	14.7	1.32	%	Li_2O	209
Lithium	**Kathleen Valley**	Liontown Resources Ltd	PFS	Li, Ta	156.0	1.40	%	Li_2O	2,184

Source: Australian Critical Minerals Prospectus 2020

Potential collaboration opportunities

India foresees strong growth in lithium demand, implying that securing lithium supply is a priority for the country. Australia has resources to help meet India's increasing demand.

Plans to set up battery manufacturing units in India will lead to demand for lithium raw materials for processing and assembly, provided cell chemistry and allied manufacturing facilities are set up.

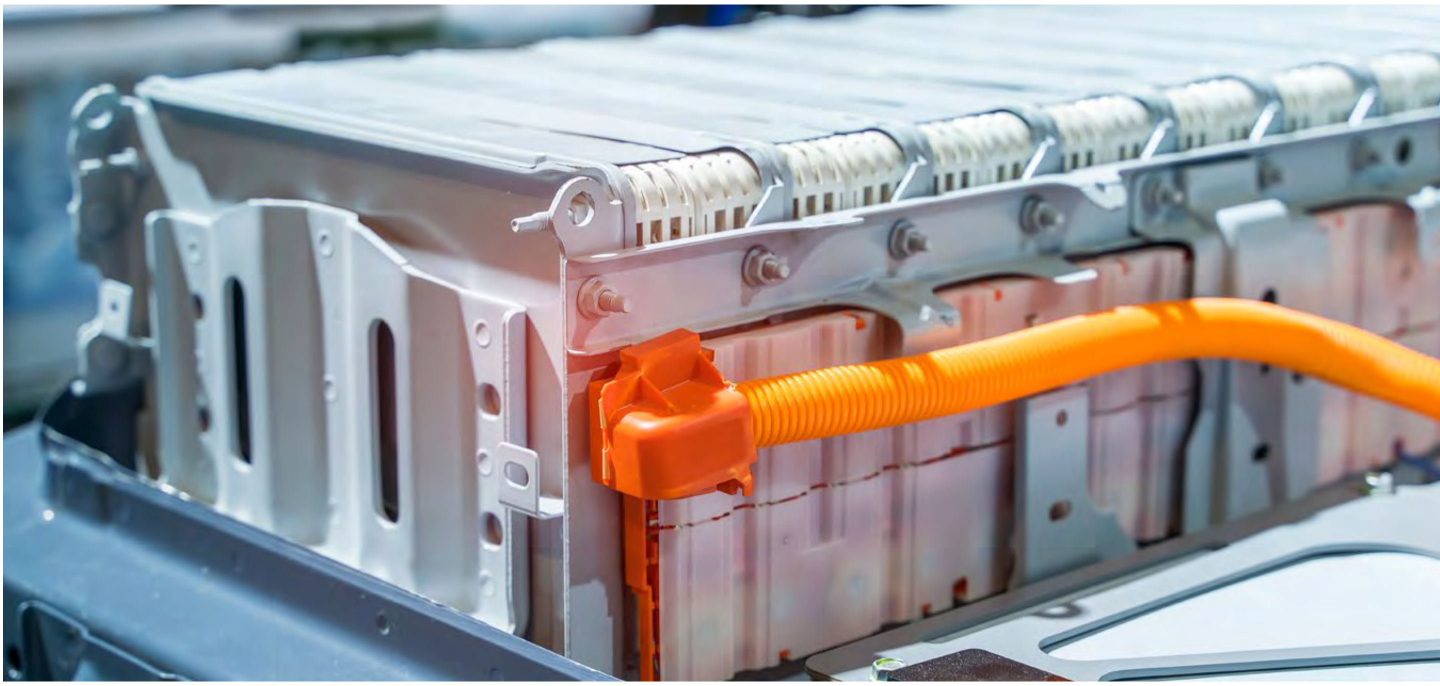
Indian manufacturers have ambitious plans for energy storage solutions but the lack of advanced cell chemistry capabilities means continued dependency on imported cells and battery packs.

Cell and related components manufacturers in Japan, Korea, the EU, and the US have shown interest in the Indian market. As a result, potential JVs could help increase production in India to cater to local demand and export to other countries.

Against this backdrop, Indian majors and JV parties could consider long-term offtake arrangements with Australian miners to secure supplies.

Key opportunities

- Australian manufacturers could ship lithium cathode active materials to active chemistry and cell manufacturers in India.
- Indian companies and JVs (including battery manufacturing technology partners) could invest in lithium metals processing capacity (lithium hydroxide, lithium carbonate etc.) in Australia.
- Indian companies and JVs (including battery manufacturing technology partners) could invest in Australian lithium mining and processing (spodumene concentrates) projects, to feed the Indian supply chain.
- Australian lithium projects at the development stage could offer opportunities for India to secure long-term offtake opportunities.
- Lithium-ion battery manufacturing in India could be further encouraged by the Indian Government, reducing import duties on lithium hydroxide, lithium carbonate, and spodumene concentrate. This would help Indian battery manufacturers become competitive with international battery manufacturers.
- Indian companies could partner with Australia's Future Battery Industries Cooperative Research Centre (CRC) on battery technology and processing to support manufacturing capabilities in India. Over this report's 10-year forecast period, new emerging battery technologies, such as silicon compounds, may be commercialised, as a replacement for graphite anodes in lithium-ion batteries.



Cobalt

Cobalt will be an important ingredient for India's shift to a low carbon economy.

By 2030, 80 percent cobalt demand is expected to be driven by increased use of lithium-ion batteries.[72] Cobalt is also widely used in a range of other specialised applications, such as superalloys, high-temperature alloys, cutting tools, magnetic materials, petrochemical catalysts, pharmaceuticals, steel, and glaze materials.

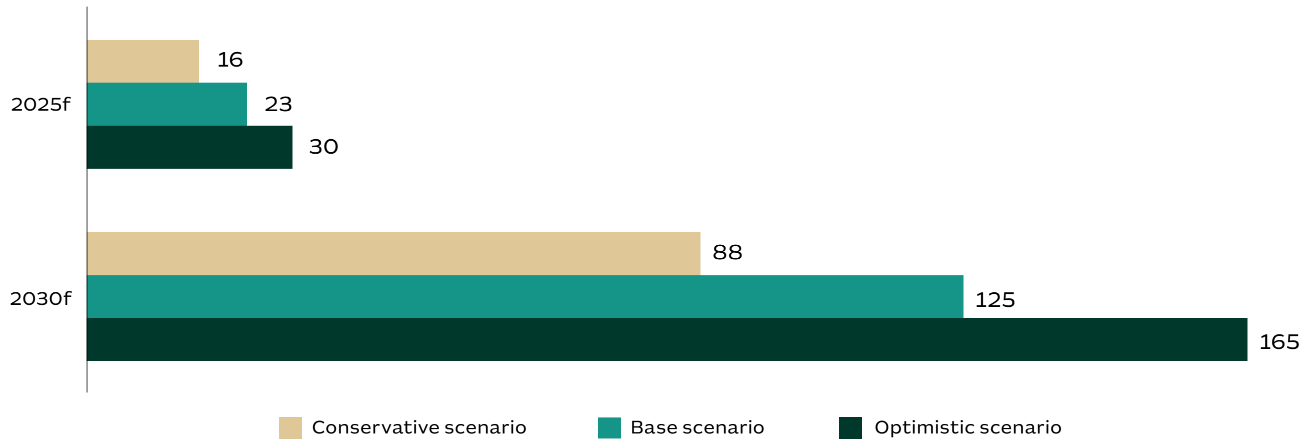
With EV market growth and absence of cobalt reserves in India, battery and cell chemicals manufacturers will need to invest upstream or form strategic alliances with mineral-rich countries to ensure security and continuity of supply.[73]

Australia is well equipped to provide stable supply on the back of significant cobalt reserves, accounting for about 19 percent of the global resources.

Indian market analysis

The Indian cobalt market was estimated to be 1–1.2 kt in 2020. It is expected to reach a cumulative demand potential of 88-165 kt by 2030.[74]

Figure 15: Cumulative Indian cobalt market demand potential (kt)[75]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	30	23	16	165	125	88

Disclaimer: The demand potential identified shall be subject to the expected development of lithium-ion battery value chain in India.

Notes:

72. UBS Report - Battery Raw Materials – November 2020
73. Australian Critical Minerals Prospectus 2020
74. Analysis based on publicly available information in following government and other reports- NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities ; -19; By 2024, nearly half of new three wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020
75. Analysis based on publicly available information in following government and other reports- NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new three-wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020. While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.

Cobalt's high melting point and ferromagnetic properties make it suitable for two major applications: lithium-ion battery cathodes and superalloys. Cobalt demand for lithium-ion battery cathodes, which are primarily used for EVs and ESS and other batteries, could drive ~80 percent of the demand by 2030.

The residual demand from other applications, including superalloys, magnets, and industrial materials, could contribute about 20 percent to the cobalt demand potential by 2030.[76]

As increase in demand for cobalt is expected to differ amongst end-use industries. Cobalt consumption across Indian industries is also likely to vary from 2020 to 2030.

Table 7: Forecast Indian cobalt market by end-use segment[77]

End-use segment	2020e	2025f	2030f
Electric vehicle batteries	25%	56%	63%
Other batteries	35%	18%	15%
Other non-battery uses (superalloys, magnets, pigments, others)	40%	26%	22%

The three dominant cathode chemistries used for manufacturing lithium-ion batteries are LFP, NMC, and NCA. Depending on battery chemistries and configurations, cobalt content usually varies by 10–30 percent of cathode weight in NMC and 10–15 percent in NCA.[78] At present, 85–90 percent of lithium-ion batteries are manufactured using NMC- or NCA-based technologies.

A shift towards chemistries with reduced cobalt concentrations is expected over the next decade.[79] Cobalt content of lithium-ion batteries is likely to be reduced rather than eliminated, with a lower cost mineral (such as nickel) to be used as a substitute without affecting battery performance.

While 'cobalt-free' battery technologies are being explored due to price, supply, and sustainability considerations, lithium-ion battery designs with cobalt cathodes are still likely to dominate the battery market in the medium to long term (refer figure 11).

Notes:

76. Analysis based on information publicly available in following government and other reports- NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new 3-wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020. While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers. Other Batteries includes demand from solar pumps & micro grid, Railway – traction, Telecom, DG replacement and Captive power plants; While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.
77. Analysis based on information publicly available in following government and other reports -NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new 3-wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020. While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers. Other Batteries includes demand from solar pumps & micro grid, Railway – traction, Telecom, DG replacement and Captive power plants; While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.
78. Cobalt: demand-supply balances in the transition to electric mobility, JRC Science for Policy Report
79. The Ultimate guide to cobalt market 2021-2030, crux investor

Key industry participants

Most cobalt used in manufacturing in India is imported in various forms – ores, concentrates, sulphates, hydroxides, and oxides – depending on end-use industry requirements.

Indian manufacturers, such as Nicomet Industries Limited in Cuncolim, Goa, and Rubamin Limited in Halol, Gujarat, have developed capabilities to process cobalt in India. Nicomet uses hydrometallurgy solvent extraction technology to produce cobalt metal and its derivatives.[80]

Rubamin has developed ecotechnology to recover elements in spent catalysts. Rubamin manufactures high-grade cobalt sulphate for non-battery applications, including animal health formulations, catalysts, fertilisers, and dyes.[81]

India's lithium-ion battery manufacturing sector is in early stages of development. The companies listed in the table below are actively studying and planning battery production plants in India. JVs with international battery manufacturing technology partners will facilitate development of India's lithium-ion battery capability.

Table 8: Potential end-use industries and players[82]

End-use segment	Technology/ products	End-use industries	Mineral specification	Key industry players	Key geographical locations
Cobalt processing	Cobalt sulphate	Lithium-ion batteries (LCO, NMC, and NCA) Non-battery applications, including animal health formulations, catalysts, fertilisers, and dyes	Cobalt concentrate	Lithium-ion battery manufacturers Nicomet Industries Limited and Rubamin Limited	Cuncolim, Goa and Halol, Gujarat
Battery/ electrode/ cell chemistry production	Lithium-ion battery (LCO, NMC, and NCA)	Electronics, EVs, and construction and mining equipment	Battery-grade cobalt sulphate heptahydrate ($CoSO_4 \cdot 7H_2O$)	Exide Industries Limited, Tata Chemicals Limited, HBL Power Systems Limited, Amara Raja Batteries Limited, Mahindra Electric Mobility Limited, TDSG, and Contemporary Amperex Technology Co.*	Major EV battery components and chemistry manufacturing clusters include Dholera and Hansalpur in Gujarat; Chandanvelli-Sitarampur in Hyderabad; Divitipalli in Telangana; Hubli and Dharwad in Karnataka; and other planned locations across the country
Superalloys	Cobalt-based superalloys	Defence, aerospace and automotive	Cast and unwrought cobalt alloy metals	Mishra Dhatu Nigam Limited (MIDHANI)	Hyderabad

*https://www.amararaja.com/, https://www.mahindra.com/news-room/press-release/mahindra-and-lg-chem-collaborate-for-li-ion-battery-technology,https://www.tatachemicals.com/Asia/Products/Specialty-chemistry/Material-Sciences/energy-storage-solutions, https://www.businesstoday.in/current/corporate/amara-raja-sets-up-research-hub-to-develop-lithium-ion-cells-at-tirupati/story/431895.html

Notes:

80. https://ibm.gov.in/writereaddata/files/09022020154028Cobalt_2019.pdf
81. https://rubamin.com/
82. Based on primary and secondary research, news articles, annual reports

Supply scenario in India

Global cobalt reserves are highly concentrated in a handful of countries, including the Democratic Republic of Congo (DRC), Australia, Zambia, and Cuba.

In 2018, about 98 percent global cobalt production was through extraction as a by-product of nickel and copper.[83] This means that cobalt prices are dictated by nickel and copper prices. About 70 percent of cobalt production is concentrated in the conflict-prone DRC. In addition to the resource concentration in the DRC, about 50 percent of cobalt processing is concentrated in China.

In 2019, global economic resources of cobalt were 7,200 kilo tonnes of cobalt. India had 44.91 Mt of cobalt reserves, according to the National Mineral Inventory.[84] It does not currently produce cobalt. However, it does have modest cobalt refining capacity estimated at 2 kt (of cobalt sulphate) annually, with Nicomet and Rubamin the leading manufacturers.

India imports cobalt in various forms, including as waste and scrap, which accounted for about 1.5 kt in 2019 and 1 kt in 2020.[85]

India primarily imports cobalt ores, oxides, and hydroxide from Belgium, China, and Finland. It imports cobalt sulphate from Finland and China.

Table 9: Indian imports of cobalt concentrates and compound[86]

Import product description	HS code	2019		2020	
		Volume (kt)	Value (A$ million)	Volume (kt)	Value (A$ million)
Cobalt ores, oxide, and hydroxide	2605, 2822	0.27	10.6	0.24	8.85
Cobalt sulphate	2833	0.20	2.12	0.26	2.62
Cobalt mattes, powder, and other intermediate products of cobalt metallurgy, including waste and scrap	8105	1.30	92.96	0.76	54.12

Notes:

83. EV- Charging towards a bright future, Avendus Report, July 2020
84. Indian Mineral Yearbook, 2020 – Cobalt, https://ibm.gov.in/writereaddata/files/09022020154028Cobalt_2019.pdf
85. UNCOMTRADE, ITC Trade map and India Trade Statistics
86. UNCOMTRADE and India Trade Statistics

Figure 16: Imports of cobalt sulphate in 2020[87]

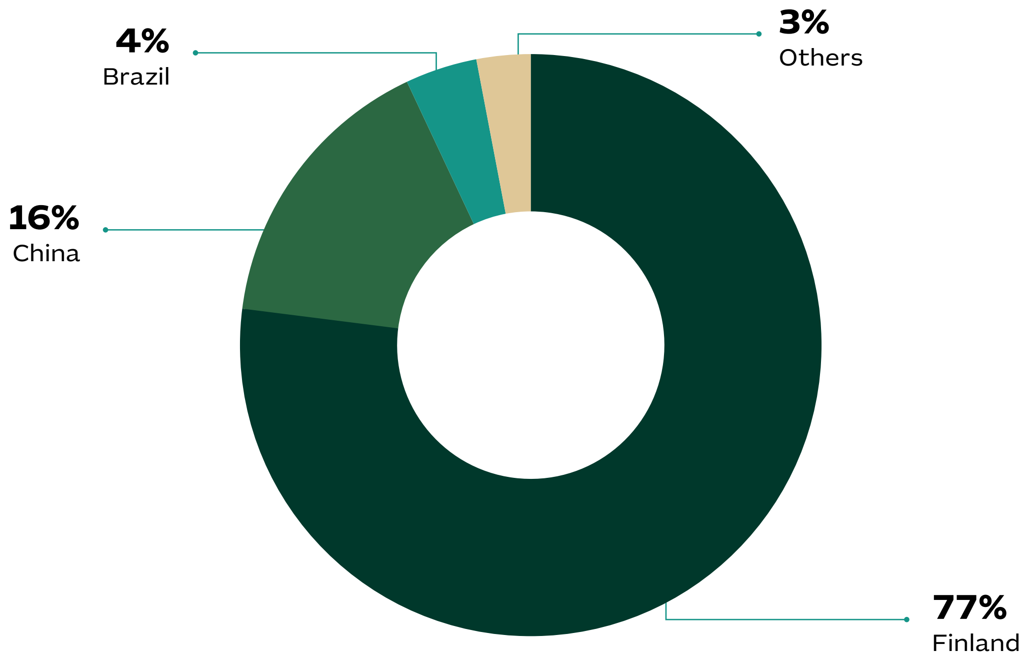
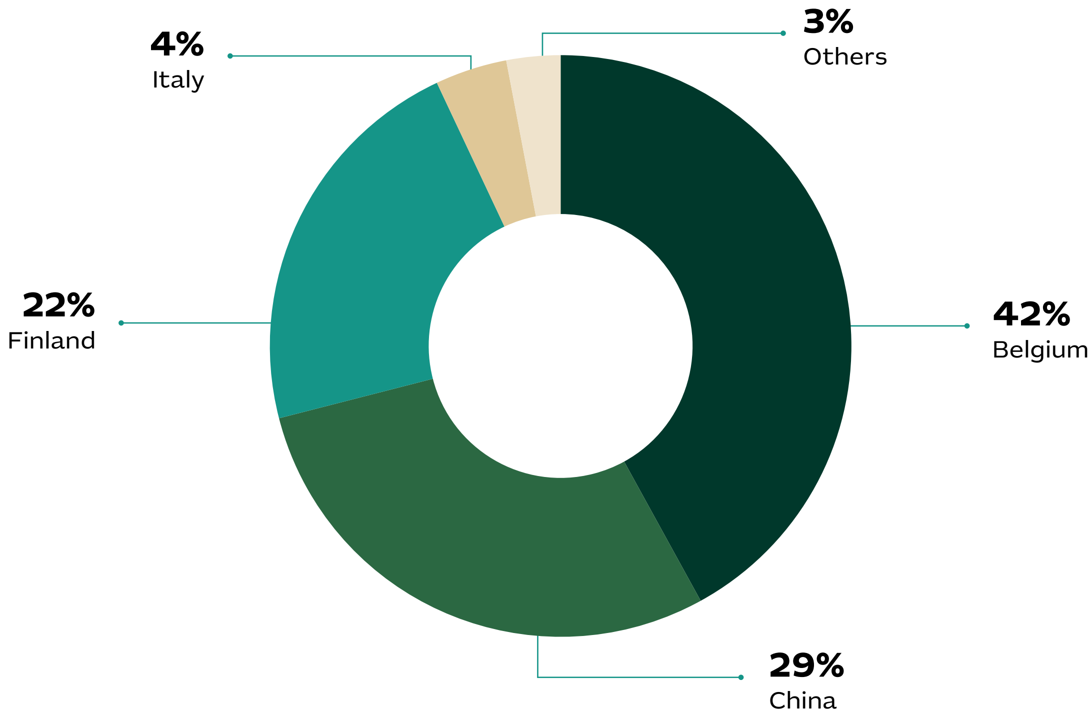


Figure 17: Imports of cobalt ores, oxides, and hydroxides in 2020[88]



Notes:

87. UNCOMTRADE and India Trade Statistics
88. UNCOMTRADE and India Trade Statistics

The Indian Government has imposed higher duties on cobalt chemicals and intermediates to support local manufacturing of lithium-ion batteries, EVs, and ancillary products. The table below lists government duties imposed on various forms of imported cobalt.

Table 10: Indian import duties on cobalt products from April 2021[89]

Category	HS code	BCD	SWS	IGST	Total duties
Cobalt ores and concentrates	2605	5%	10%	5%	10.8%
Cobalt oxide, hydroxide, and sulphate	2822, 2833	10%	10%	28%	42%
Cobalt mattes powder and other intermediate products of cobalt metallurgy, including waste and scrap	8105	5%	10%	18%	24.5%

Note: The IGST is applicable on both imports and Indian manufacture and is an eligible 'input tax credit', which can be offset against GST liability.

While India's duties on cobalt ores and concentrates are comparatively low (10.8 percent), almost all of cobalt is a by product of copper or nickel mining, which include cobalt sulphate or cobalt metal. There is a need to reduce the duty on these mid-stream cobalt products to increase the competitiveness of India's lithium-ion battery manufacturing.

International cobalt prices stood at about A$ 49,530 a tonne in 2019. These are projected to reach A$ 80,400 a tonne by 2030.[90] Limited cobalt processing capacity in India provides an opportunity for Australian mines to supply battery-grade cobalt sulphate.

Indian battery and chemical manufacturers and EV organisations can evaluate entering into long-term arrangements with upstream investment projects to secure cobalt supply.

The opportunities presented by the global supply chain and limited domestic resources make India a strong market proposition for Australian cobalt suppliers.

Australian supply capability

Australia ranks second in the world for cobalt economic resources that were estimated at 1,399 kt in 2019 (19 percent of the global economic cobalt resources).[91] In 2019, Australia produced 5.7 kt of cobalt, constituting 5 percent of the global production and ranking third across the globe after DRC and Russia.

Australia is well equipped with large cobalt reserves and a cobalt project pipeline to sustain production growth, making it a viable competitor to DRC and China in the longer term.

Australia's cobalt industry is driven by a strong nickel mining industry, in contrast to other markets where cobalt is extracted mostly from copper mining.

Australia accounts for 7 percent of the global nickel production and hosts 24 percent of the world's nickel resources.[92] Historically, cobalt production stemmed from growth in nickel sulphide mining in Western Australia. However, more recent developments have seen cobalt production rise from lateritic nickel operations, also in Western Australia.

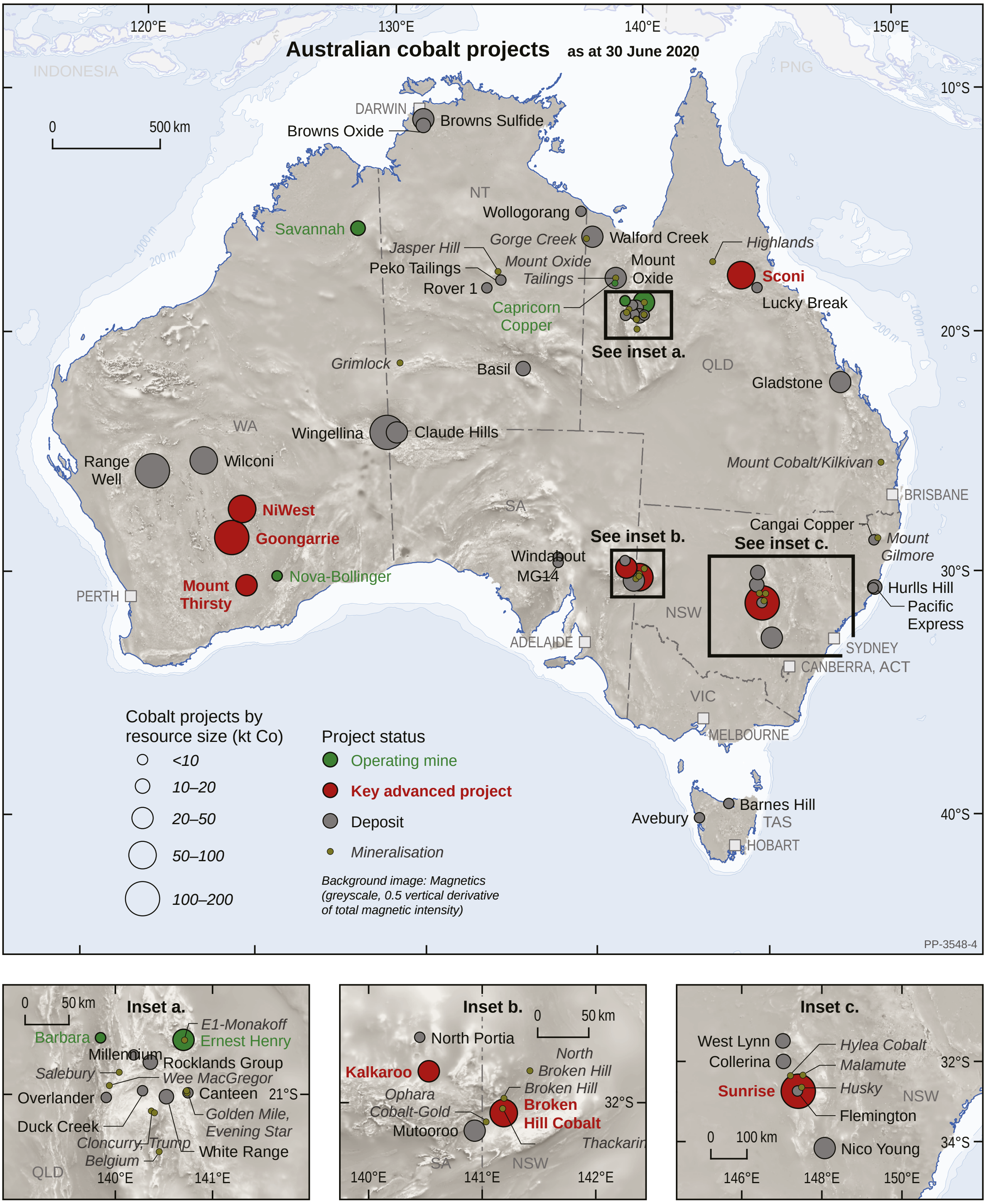
Several advanced Australian cobalt development projects are seeking funding for construction, representing an excellent opportunity for Indian battery manufacturers and EV producers.

International battery technology partners could also participate in developing Australian cobalt projects as strategic partners to secure long-term cobalt sulphate supply.

Notes:

89. CBIC -Ministry of Commerce, GOI
90. UBS Report – Battery Raw Materials – November 2020
91. Australian Critical Minerals Prospectus 2020
92. Geoscience Australia

Figure 18: Australian cobalt projects



Source: Australian Critical Minerals Prospectus 2020

The following table highlights operating mines and a robust project pipeline to meet future cobalt requirements.

Table 11: Australia's operating mines and key advanced projects

Critical mineral	Project name	Company	Project status	Primary mineral(s)	Tonnage (Mt)	Grade	Units		Contained (kt)
Cobalt	**Savannah**	Panoramic Resources Ltd	Operating	Ni, Cu, Co	13	0.11	%	Co	14
Cobalt	**Nova-Bollinger**	IGO Ltd	Operating	Ni, Cu, Co	11.6	0.07	%	Co	8
Cobalt	**Barbara**	ASX:SOL	Operating	Cu, Au	4.8	0.03	%	Co	1
Cobalt	**Capricorn Copper**	Capricorn Copper Holdings	Operating	Cu					NA
Cobalt	**Ernest Henry**	Glencore Plc	Operating	Cu, Au					NA
Cobalt	**Sunrise**	Clean TeQ Holdings Ltd	Pre-const	Ni, Co, Sc	183.3	0.09	%	Co	162
Cobalt	**Wingellina**	Metals X Ltd	FS	Ni, Co	215.8	0.07	%	Co	151
Cobalt	**SCONI**	Australian Mines Ltd	FS	Ni, Co	75.7	0.08	%	Co	57
Cobalt	**Gladstone**	Gladstone Pacific Nickel Ltd	FS	Ni, Co	70.9	0.06	%	Co	43
Cobalt	**Mount Oxide**	Zhongjin Lingnan Mining	Care and maint	Cu, Ag	25.1	0.08	%	Co	21
Cobalt	**Rocklands Group**	CuDeco Ltd (in liquidation)	Care and maint	Cu, Au	56.7	0.03	%	Co	17
Cobalt	**White Range**	Young Australian Mines Ltd	FS	Cu, Au	29.1	0.04	%	Co	11
Cobalt	**Avebury**	Allegiance Mining Pty Ltd	Care and maint	Ni, Co	29.3	0.02	%	Co	7
Cobalt	**Range Well**	EV Metals	PFS	Ni, Cr, Co	385.3	0.04	%	Co	154
Cobalt	**Goongarrie**	Ardea Resources Ltd	PFS	Ni, Co	215.6	0.06	%	Co	131
Cobalt	**Broken Hill Cobalt**	Cobalt Blue Holdings Ltd	PFS	Co (S, Fe)	111	0.07	%	Co	79
Cobalt	**NiWest**	GME Resources Ltd	PFS	Ni, Co	85.2	0.07	%	Co	55
Cobalt	**Mt Thirsty**	Conico; Barra Resources	PFS	Co, Ni	26.8	0.12	%	Co	32
Cobalt	**Kalkaroo**	Havilah Resources Ltd	PFS	Cu, Au, Co	193.3	0.01	%	Co	23

Source: Australian Critical Minerals Prospectus 2020

Potential project cooperation opportunities

India's lithium-ion battery manufacturing ecosystem is currently restricted to battery assembly operations. Indian battery chemical and cell manufacturers must secure foreign suppliers to develop and maintain a resilient supply chain of cobalt to, in turn, support rapid transition to EVs.

Indian demand for cobalt is closely linked to the development of its lithium-ion battery value chain

Key opportunities

- A number of advanced Australian cobalt development projects are seeking funding. This presents an opportunity to involve Indian battery manufacturers and EV producers (such as Exide Industries, TDSG, and Tata Chemicals) and international battery technology partners (such as Panasonic, Samsung, and BASF), to support development of Australian projects and secure offtake arrangements.
- The majority of Australian cobalt development projects are nickel-cobalt projects. Participation in these projects would enable Indian companies and conglomerates to establish a secure nickel supply as well.
- India could reduce its import duties on cobalt sulphate and other mid-stream cobalt products to make the Indian lithium-ion battery sector more competitive.
- Indian manufacturers and JVs (including battery manufacturing technology partners) could consider investing in cobalt cathode active materials (finished precursor materials), either independently or with a buy-back arrangement through agencies such as KfW Germany or Japan International Cooperation Agency (JICA), to feed the Indian supply chain.

Graphite

Graphite is a form of elemental carbon with a high electrical and thermal conductivity and excellent thermal stability, making it suitable for a wide range of industrial applications. These applications include lithium-ion batteries, refractory products, electrodes, foundry additives, and lubricants.

The steel industry has historically shaped growth of the graphite market using electrode and refractory products. However, graphite is now becoming an increasingly important element in lithium-ion battery anodes globally.

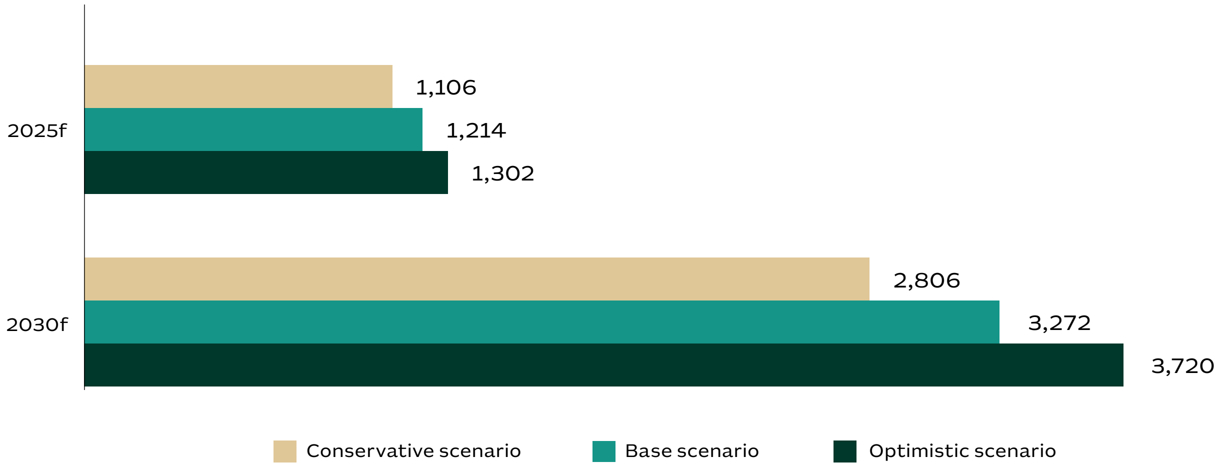
India's use of graphite in battery electrodes and chemicals is forecast to grow as it establishes its lithium-ion battery manufacturing capacity. The country's focus on cost-competitive and low-carbon production processes will drive demand for natural graphite compared with its expensive synthetic counterpart.

India is currently a net importer of natural graphite, with about 60 percent of imports sourced from China.[93] Australia's pipeline of advanced graphite development projects, including planned processing into spherical flake graphite for battery manufacturing, could support diversification of India's supply chain.

Indian market analysis

India's market for natural and synthetic graphite was estimated at 155–175 kt in 2020. It is forecast to reach an expected cumulative demand potential of 3,720 kt by 2030.[94]

Figure 19: Cumulative Indian graphite market demand potential (kt)[95]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	1,302	1,214	1,106	3,720	3,272	2,806

Disclaimer: The demand potential identified shall be subject to the expected development of lithium-ion battery value chain in India

Notes:

93. UNCOMTRADE and India Trade Statistics

94. Analysis based on publicly available information in following government and other reports - NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities ; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new three-wheelers sold will be e-autos, CRISIL ; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020 ; India is expected to replicate the global application trends; other batteries include demand from solar pumps and micro grid, Railway – traction, Telecom, DG replacement, and Captive power plants; while 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers

95. Analysis based on publicly available information in following government and other reports - NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new three-wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020; while 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.

In India, graphite demand for use in lithium-ion battery anodes, mostly for EVs and ESS, is expected to drive around 25 percent graphite demand in 2030.

The high growth rate would be a result of the anticipated rapid shift from internal combustion engines to EVs over the next decade, with demand growth expected to slow after that.

With a rise in demand for graphite expected to vary between end-use industries, graphite consumption across India's industries is likely to vary from 2020 to 2030.

Table 12: Indian graphite market forecast by end-use segment[96]

End-use segment	2020e	2025f	2030f
EV batteries	1%	6%	20%
ESS and other batteries	-	6%	6%
Electrodes	54%	46%	37%
Refractories	31%	27%	22%
Others (incl. lubricants and foundries)	14%	15%	15%

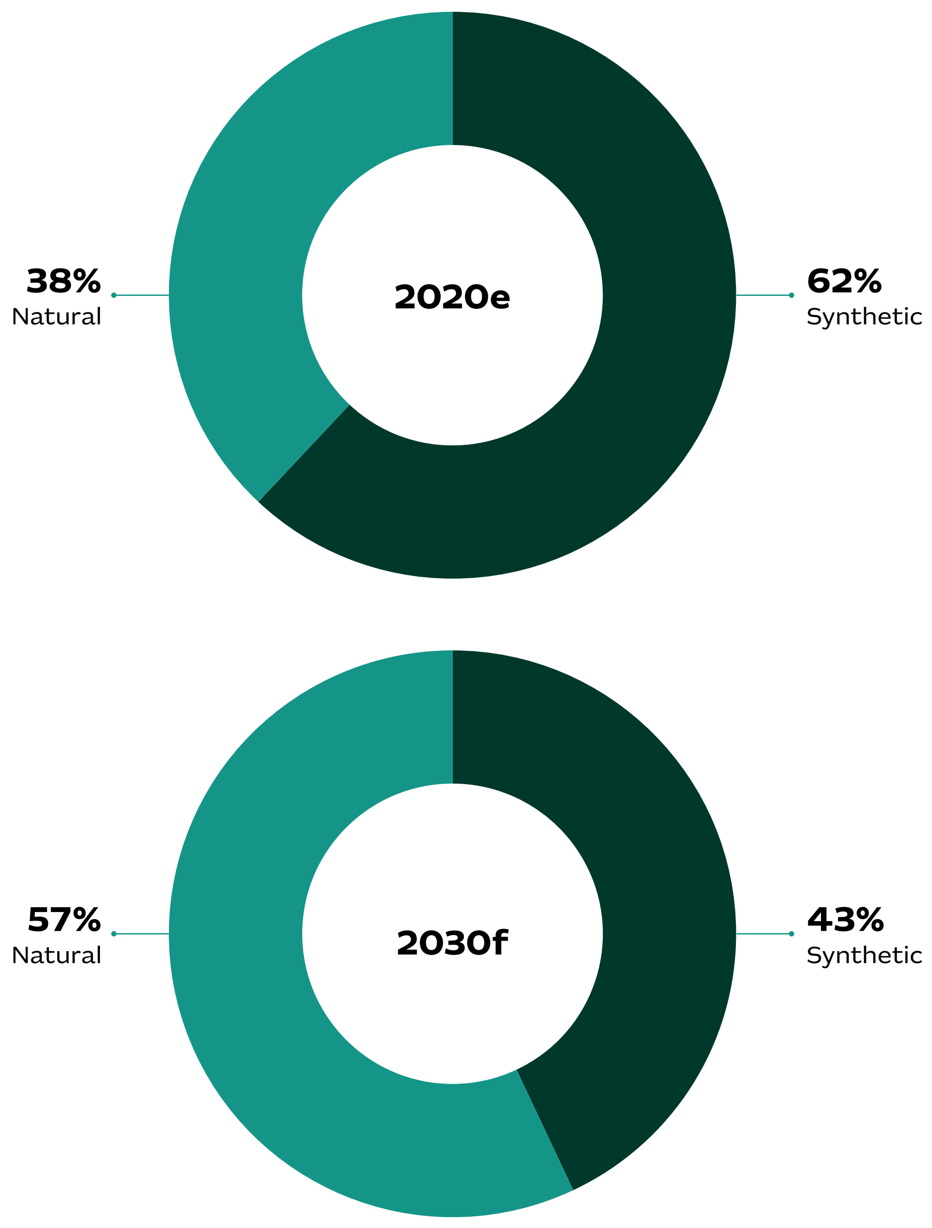
Graphite exists in two forms: natural graphite, including flake, amorphous, and crystalline, which is mined; and synthetic graphite, which is processed from petroleum coke or coal tar. Both forms compete for applications in batteries, refractories, foundries, and lubricants.

Electrodes used in electric arc furnace steelmaking primarily use synthetic graphite. This is also preferred for lithium-ion batteries due to its superior consistency and purity. However, most lithium-ion battery manufacturers use a combination of natural and synthetic graphite to balance the needs of energy density and cycle time.

Notes:

96. Analysis based on publicly available information in following government and other reports - NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new three-wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020; other batteries include demand from solar pumps and micro grid; railway – traction, telecom, DG replacement, and captive power plants

Figure 20: Indian graphite market forecast by type[97]



Anode chemistries have changed little in the past few years, but innovations to replace graphite in battery anodes with silicon and silicon composites could dampen graphite demand. However, these technologies are under development and it may be some time before commercial application becomes viable.[98]

An emerging technology breakthrough involving graphene-based batteries could boost natural graphite demand exponentially. Another application that is likely to increase demand for natural graphite is graphite sheet-based heatsinks used in power electronics.

Notes:

97. Primary research and UBS's battery raw materials, November 2020

98. UBS Report - Battery Raw Materials – November 2020

Key industry participants

India is likely to see a surge in demand for various forms of graphite from a range of players across the battery manufacturing landscape. While battery makers look to source processed SPG, demand for graphite concentrates might also arise from battery anode manufacturers.

Indian companies, such as Himadri Speciality Chemical Limited and Epsilon Carbon Private Limited have moved into graphite processing to produce SPG for battery anode material.[99, 100]

While Himadri has developed both natural and synthetic anode materials, Epsilon plans to supply synthetic anode materials. India's steel refractories and foundries will continue to drive demand for imported graphite.

Table 13: Potential target technologies and manufacturers[101]

	Technology / products	End-use industries	Mineral specification	Key industry players	Key geographical locations
Graphite Processing	**Spherical flake graphite**	Lithium-ion batteries	Flake graphite	Himadri Speciality Chemicals Limited, Epsilon Carbon Private Limited	Howrah and Hooghly (West Bengal), Korba (Chhattisgarh), and Vishakhapatnam (Andhra Pradesh)
Battery production	**Lithium-ion batteries (LFP graphite and LMO/ LCO graphite battery cells)**	Electronics, EVs, construction and mining equipment	SPG	Exide Industries Limited, HBL Power Systems Limited, Amara Raja Batteries Limited, Mahindra Electric Mobility Limited, TDSG and Contemporary Amperex Technology Co.*	Major EV battery manufacturing clusters include Dholera and Hansalpur in Gujarat; Chandanvelli-Sitarampur in Hyderabad; Shahabad and Divitipalli in Telangana; Hubli and Dharwad in Karnataka; and other planned locations across the country
Refractories	**Oxide-carbon refractories, refractory products for steel casting, and unshaped carbon-containing refractories**	Steel, cement, ceramics, and glass	SPG (92–94% total graphitic carbon (TGC)) Flaked graphite (90–99% TGC) Flaked graphite (85–94% TGC)	TRL Krosaki Refractories, RHI India Private Limited, Dalmia-OCL Limited, Carborundum Universal Limited and IFGL Refractories Limited	East Godavari and West Godavari in Andhra Pradesh; Vriddhachalam in Tamil Nadu; Asansol in West Bengal; and Jharsuguda in Odisha are amongst clusters of Micro, Small, and Medium Enterprises (MSMEs). Several other manufacturers are spread around the country

*https://www.amararaja.com/, https://www.mahindra.com/news-room/press-release/mahindra-and-lg-chem-collaborate-for-li-ion-battery-technology,https://www.tatachemicals.com/Asia/Products/Specialty-chemistry/Material-Sciences/energy-storage-solutions, https://www.businesstoday.in/current/corporate/amara-raja-sets-up-research-hub-to-develop-lithium-ion-cells-at-tirupati/story/431895.html

Notes:

99. https://www.himadri.com/advanced_carbon_materials

100. https://www.epsiloncarbon.com/press/press-release/epsilon-advanced-materials-forays-into-battery-material-business-by-commissioning-manufacturing-facility-to-produce-synthetic-graphite-anode-materials-for-lithium-batteries

101. Based on Primary and secondary research

	Technology / products	End-use industries	Mineral specification	Key industry players	Key geographical locations
Refractories	**Crucibles (clay bound)**	Steel, cement, ceramics and glass	Flaked graphite (85–94% TGC)	Zircar Refractories Limited, HEG Limited, Graphite India Limited, Pandian Graphites (India) Limited, Rahul Graphites Limited and SLV Fortune Industries India Private Limited	Rajahmundry in Andhra Pradesh has a cluster of graphite crucibles manufacturing SMEs, but prominent players have foundries across the country
Foundries	**Foundry coatings (iron foundries and non-ferrous castings)**	Automotive, electric motors, food processing	Amorphous and flaked graphite (≥85% TGC) – used as carbon additive to produce grey iron and to reduce chill depth in grey cast iron	Hinduja Foundries Limited (part of Ashok Leyland), Electrosteel Castings Limited, Nelcast Limited and other MSMEs	Major foundry clusters include Howrah in West Bengal; Batala, Jalandhar and Ludhiana in Punjab; Agra in Uttar Pradesh; Pune, Kolhapur, Sholapur and Mumbai in Maharashtra; Rajkot and Ahmedabad in Gujarat; Belgaum in Karnataka; Coimbatore and Chennai in Tamil Nadu. Each of these foundries caters to specific end-use markets
Lubrication	**Dry lubricant**	Automotive, textiles and general industrial manufacturing	Flaked graphite (96–98% TGC) needs low grit graphite (ultra-high purity)	Indian Oil Corporation Limited, Bharat Petroleum Corporation Limited, Gulf Oil Lubricants India Limited (part of Hinduja Group), Valvoline Cummins Private Limited, ExxonMobil Lubricants Private Limited, Elf Lubricants India Limited, GS Caltex India Private Limited and Tide Water Oil Co. (India) Limited	Players are spread across the country

Supply scenario in India

Natural graphite is globally abundant, with world economic resources of 308 Mt of graphite in 2019. In 2020, global production was estimated to be about 1.1 Mt, primarily in China, with the rest of the world accounting for about 40 percent of the global supply.[102]

China is also the major supplier of natural graphite for EV battery anode material, with the world's top three producers based in the country. In 2019, Mozambique was the world's second-largest graphite producer at 100 kt (9 percent), followed by Brazil with 96 kt (9 percent).

India is estimated to have a total of 194 Mt of graphite, with 7 Mt of reserves, according to the National Mineral Inventory.[103] It is a significant natural graphite producer, accounting for an estimated 39.4 kt in 2018–19.[104]

However, India remains a net importer of natural graphite. Imports accounted for about 45 kt and 39 kt of natural graphite in 2019 and 2020, respectively, with China supplying about 60 percent of the total imports.[105] India imported 52 kt and 46 kt of artificial graphite in 2019 and 2020, respectively.[106]

Beneficiation is a process to render mined graphite as more economic. Graphite miners operating prominent beneficiation plants in India include Chotanagpur Graphite Private Limited in Jharkhand, Agarwal Graphite & Carbon Products Private Limited in Daltonganj, T.P. Minerals Private Limited in Sambalpur, Tirupati Graphite Private Limited in Jharkhand, and Tamil Nadu Minerals Limited in Sivaganga.

Table 14: Indian imports of natural graphite[107]

Import product description	HS code	2019		2020	
		Volume (kt)	Value (A$ million)	Volume (kt)	Value (A$ million)
Natural graphite powder and flakes	25041010, 25041020, 25041090	43.84	28.61	37.76	21.95
Other forms of natural graphite	25049010, 25049090	1.15	1.21	0.88	0.82

Notes:
102. https://pubs.er.usgs.gov/publication/mcs2021
103. Indian Mineral Yearbook, 2019 - https://ibm.gov.in/writereaddata/files/07072020143852Graphite_2019.pdf
104. https://ibm.gov.in/writereaddata/files/07072020143852Graphite_2019.pdf
105. UNCOMTRADE
106. UNCOMTRADE
107. UNCOMTRADE and India Trade Statistics

The following graphics show that India imports the bulk of its natural graphite from China, Madagascar, and Mozambique.

Figure 21: Imports of natural graphite powder and flakes in 2020[108]

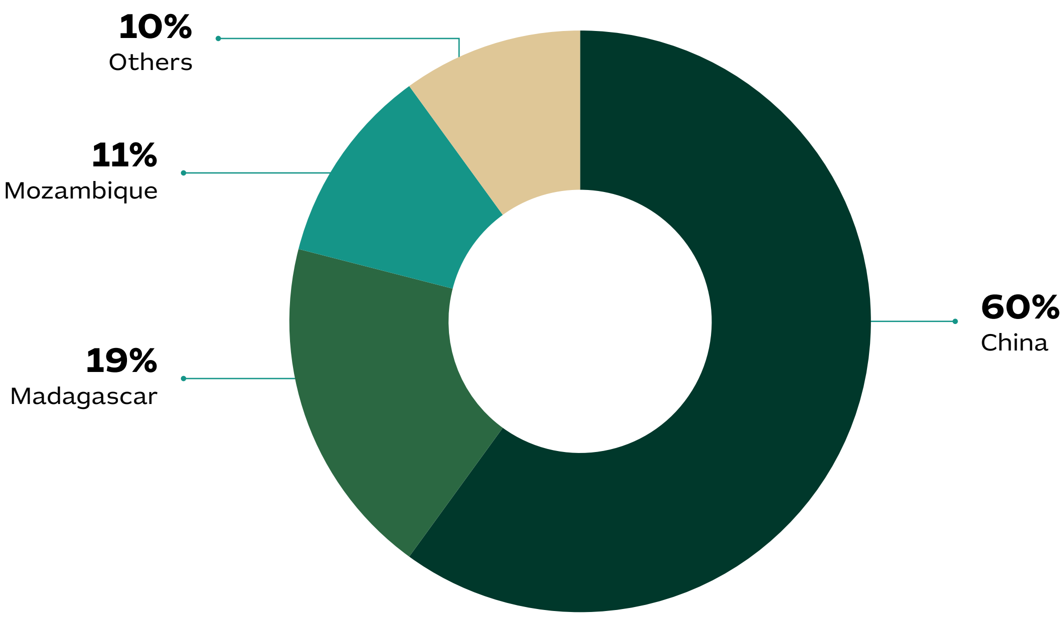
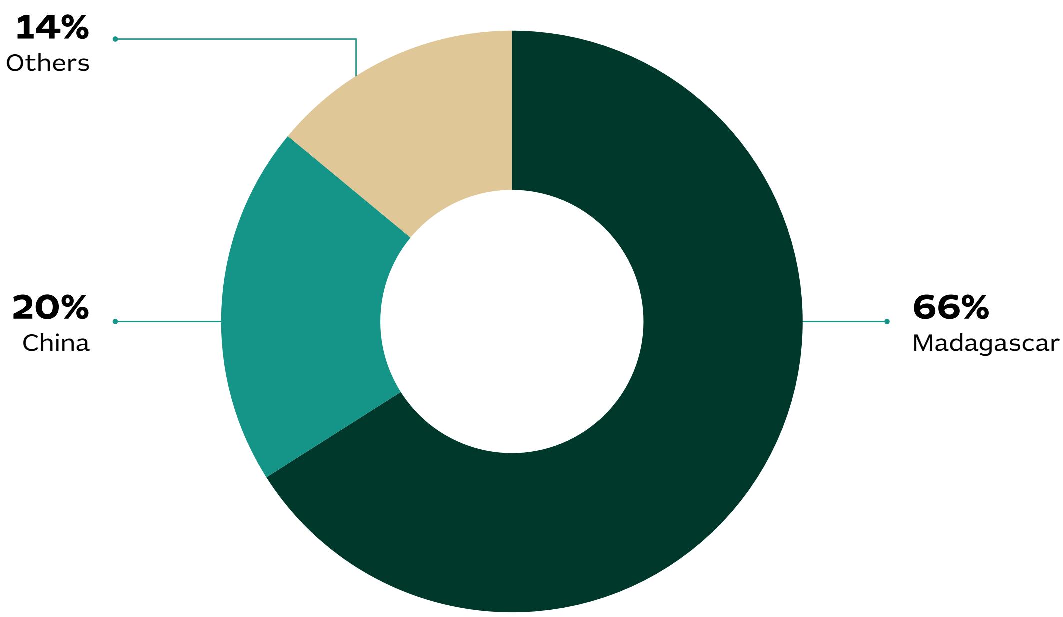


Figure 22: Imports of other forms of natural graphite in 2020[109]



Notes:
108. UNCOMTRADE and India Trade Statistics
109. UNCOMTRADE and India Trade Statistics

The following table shows import duties imposed by the Indian government on natural graphite.

Table 15: Indian import duties on natural graphite from April 2021[110]

	HS code	BCD	SWS	IGST	Total duties
Natural graphite	2504	10%	10%	5%	16.55%

Note: The IGST is applicable on both imports and Indian manufacture and is an eligible 'input tax credit', which can be offset against GST liability.

The free on board China price for graphite flake, which is the most commonly traded form of graphite, was about A$750–1,200 a tonne in 2019. Prices are forecast to increase, potentially reaching A$ 1,190–1,555 a tonne by 2030.[111]

India is likely to remain a net importer; Indian buyers will seek to secure supplies at competitive prices, providing an opportunity for international suppliers.

The expected surge in demand for battery-grade anodes due to the forecast rise of EVs in India in the latter half of the decade will create opportunities for Australian suppliers of natural graphite to establish strategic supply relationships with Indian companies.

Australian supply capability

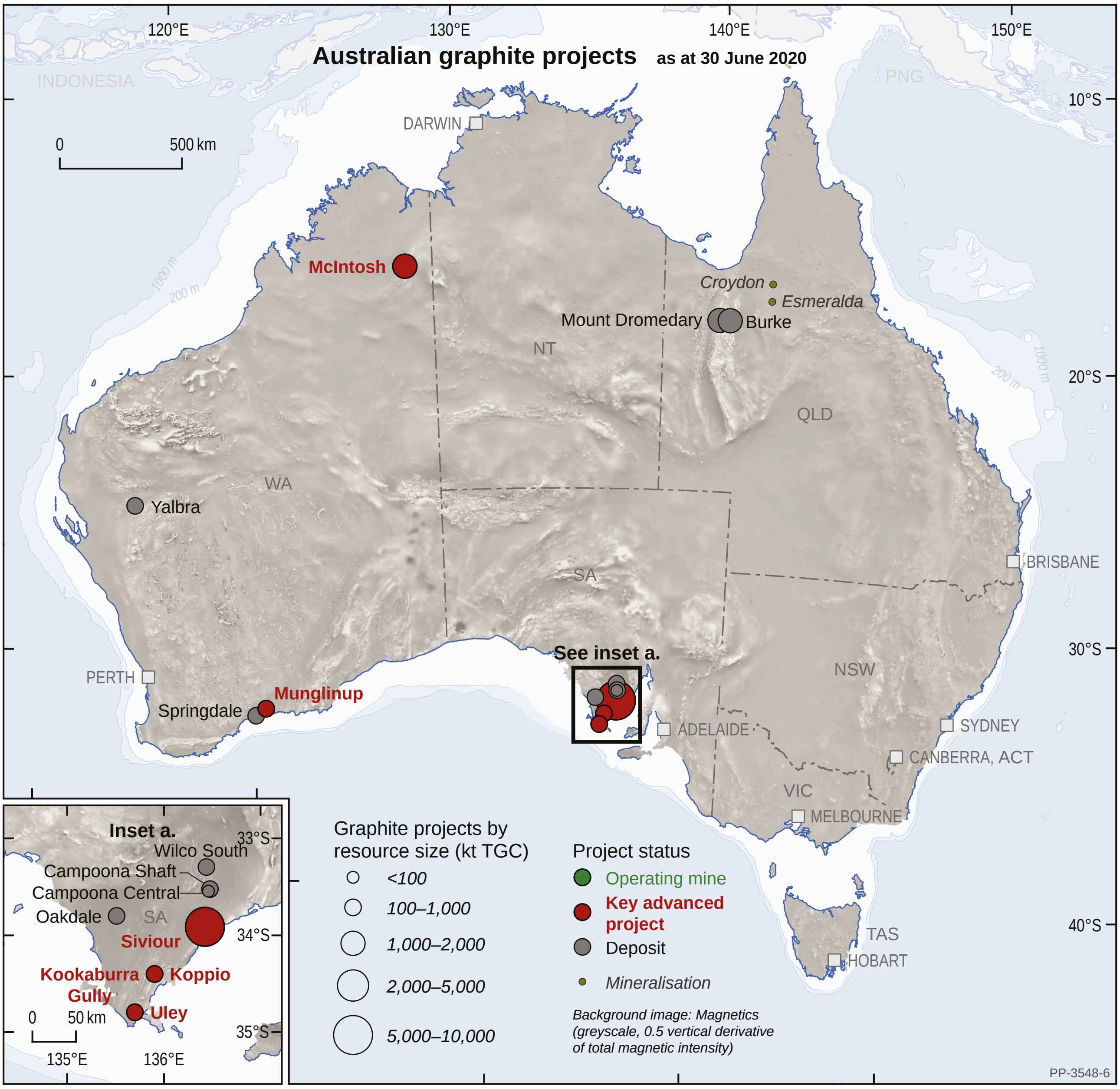
Australia ranks seventh globally for EDR of natural graphite with an estimated 7.97 Mt in reserves across South Australia, Queensland, and Western Australia in 2019.[112]

Australia has a number of advanced projects to mine flake graphite. Project proponents also plan to develop battery anode material manufacturing facilities to convert graphite concentrate into high-value SPG for the lithium-ion battery market.

Notes:

110. CBIC -Ministry of Commerce, GOI
111. UBS Report - Battery Raw Materials – November 2020
112. Australian Critical Minerals Prospectus 2020

Figure 23: Australian graphite projects



Source: Australian Critical Minerals Prospectus 2020

Table 16: Australia's planned graphite projects

Critical mineral	Project name	Company	Project status	Primary mineral(s)	Tonnage (Mt)	Grade	Units		Contained (kt)
Graphite	**Siviour**	Renascor Resources Ltd	FS	Graphite	87.4	7.50	%	TGC	6,600
Graphite	**Munglinup**	Mineral Commodities Ltd	FS	Graphite	8.0	12.20	%	TGC	975
Graphite	**Uley**	Quantum Graphite Ltd	Care and maint	Graphite	6.3	11.10	%	TGC	697
Graphite	**Kookaburra Gully**	Lincoln Minerals Ltd	FS	Graphite	2.0	15.20	%	TGC	309
Graphite	**McIntosh**	Hexagon Energy Materials	PFS	Graphite	23.8	4.45	%	TGC	1,060

Source: Australian Critical Minerals Prospectus 2020

Potential project cooperation opportunities

India's demand for graphite is likely to grow significantly due to the development of the battery electrodes and battery chemicals industry. Global supply dynamics will be affected by the concentration of the supply of natural graphite and SPG in just a few regions.

Australian companies have established capabilities in battery anode materials. Syrah Resources has opened the first vertically integrated production facility for active anode material from natural graphite in Louisiana, US.

EcoGraf Limited has commissioned a SPG purification plant in Kwinana, Western Australia utilising cost-effective, environmentally friendly (HF-free) technology.

Australian suppliers can partner with Indian Original Equipment Manufacturers (OEMs) to bring these technologies to India and capitalise on the increasing demand for battery materials. In addition, they can transfer technology for recycling and/or recovery of carbon and establish a sustainable circular economy for the segment.

Key opportunities

- Australian graphite suppliers could explore offtake opportunities with traditional downstream industries, such as refractories, electrode makers, and steelmakers, in India.
- Australian companies could initiate dialogues with battery chemicals and cell manufacturers in India to assess market readiness for supply of natural graphite.
- A number of advanced Australian graphite development projects are seeking funding for project construction. They could seek investment and strategic partnerships with Indian battery and EV manufacturers for developing Australian graphite projects and/or processing in Australia or in India. International battery technology partners could also be involved.
- Companies could examine the possibility of forming Australia-India JVs for graphite processing, and recycling and recovery technologies, to ensure compliance with sustainable mining practices.

Nickel

Key growth drivers for nickel include the rise in the alloy and stainless-steel sectors and the growth of lithium-ion battery manufacturing in India. Battery chemistries requiring nickel are necessary for applications in EVs and ESS. Nickel is also used to produce superalloys and microphone capsules.

Coated steel, aluminium, plastics, and plain chromium steel are common substitutes for stainless steel and nickel alloys in many construction and transportation applications. Ultra-chromium stainless steels are being replaced by austenitic grades in construction.

Non-nickel specialty steels are also used in the oil and petrochemical sectors. To mitigate corrosion, titanium alloys or specialty plastics are used as substitutes for nickel alloys in applications.

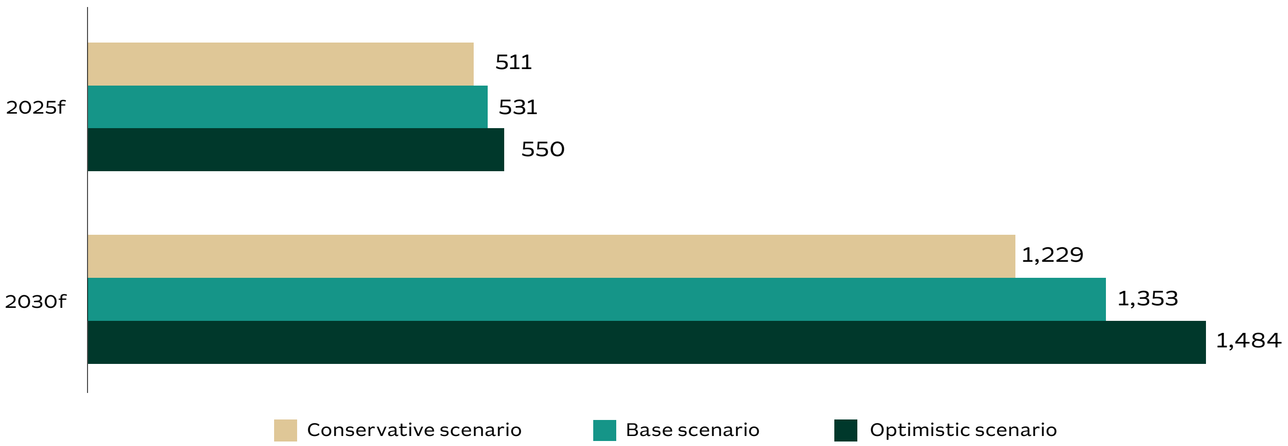
India is focusing on exploring nickel for commercial sale, using advanced technologies and strategic alliances with nickel-rich suppliers. India will have to depend on imports for this metal till a technology to recover nickel from the overburden of chromite ore in Odisha is established on a commercial scale.

Australia has the world's largest EDR (24 percent) of nickel and is the sixth-largest producer. Australia has the potential to both increase nickel supplies to the established alloy and stainless steel sectors, and meet anticipated demand for nickel chemistry batteries in India.

Indian market analysis

India's nickel market was estimated at 60–62 kt in 2020. It is expected to reach a cumulative demand potential of 1229-1484 kt by 2030[112]

Figure 24: Cumulative Indian nickel demand potential (kt)[113]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	550	531	511	1,484	1,353	1,229

Disclaimer: The demand potential identified shall be subject to the expected development of lithium-ion battery value chain in India

Notes:

113. Analysis based on publicly available information in following government and other reports - NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new 3-wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020; While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.

NCA and lithium NMC oxide batteries are dominant in EVs. India's demand for these and other new lithium-ion batteries containing nickel is likely to increase.

In India, nickel is also used as an alloy metal in stainless steel and nickel cast iron production, with applications mainly in chemical plants and turbines. It is also used as a catalyst in pesticides and fertilisers. Nickel sulphate is used in plating and green-tinted glasses.

Various end-use industries for nickel are expected to grow at different rates, with the proportions of nickel used across India's industries likely to change slightly over the coming decade.

Table 17: Indian nickel market forecast by end-use segment[114]

End-use segment	2020e	2025f	2030f
Stainless steel and plating	90%	80%	75%
EVs	4%	10%	15%
Other batteries	1%	6%	8%
Others (including superalloys, coins, and chemicals)	5%	4%	2%

Key industry participants

Much of the nickel currently imported for use in the alloy and stainless steel sector is in the form of lower-grade nickel alloys, such as ferro nickel. Nickel has a wide range of applications in the engineering and electrical industries due to its alloying capacity.

Nickel is also used for chemical research or as an intermediate product in the metallurgical industry. India's nickel end-user industry potential and Australia's substantial reserves present a viable case for collaboration to secure and enhance nickel supply to India.

Table 18: Potential target technologies and manufacturers[115]

Segment	End-use industries	Mineral specification	Key industry players	Key geographical locations
Stainless steel	Power generation, automobile sector, consumer durables, defence, chemical plants, food processing	300 series austenitic (Cr Ni)	Jindal Stainless Limited, MIDHANI, Welspun, Mukand Limited	Delhi, Kolkata, Odisha, Mumbai, and Ahmedabad are major geographical hubs for stainless steel

Notes:

114. Analysis based on publicly available information in following government and other reports - NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new 3-wheelers sold will be e-autos, CRISIL; EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020. *India is expected to replicate the global application trends. * Other Batteries includes demand from solar pumps & micro grid, Railway – traction, Telecom, DG replacement and Captive power plants
115. Secondary research and Industry sources

Segment	End-use industries	Mineral specification	Key industry players	Key geographical locations
EV batteries	Electronics, EVs, construction, mining equipment	NCA and NMC lithium-ion battery cathodes use 80% and 33% nickel, respectively	Tata Chemicals, HBL Power Systems, TDSG, Aquachem Enviro Engineers Pvt. Ltd. (AEEPL), and Contemporary Amperex Technology	Major EV battery manufacturing clusters include Dholera and Hansalpur in Gujarat; Chandanvelli-Sitarampur in Hyderabad; and Divitipalli in Telangana, with more planned across India
Superalloys and plating	Highly specialised industrial, aerospace, and military applications	Nickel-based, iron-based, cobalt-based	MIDHANI, Super Alloy Castings Pvt Limited, Labdhi Engineering Co.	Hyderabad and Bangalore are hubs for significant superalloy manufacturing in India

Supply scenario in India

Nickel concentrations naturally occur in sulphide and laterite ores. Nickel laterite ores are abundant in Brazil, Cuba, Indonesia, the Philippines, and New Caledonia, while nickel sulphide deposits are found in Russia, South Africa, and Canada.

Australia has both laterite and sulphide deposits. Modern exploration technologies are assisting with the discovery of new nickel sulphide deposits in Australia. Deep-sea mining is another budding technology to explore manganese nodules containing large amounts of nickel and cobalt.

India's ROM ore resources of nickel are estimated at 189 Mt, according to the National Mineral Inventory. Nickel is found as oxides, silicates, and sulphides. It is present as an oxide in Odisha, which has 93 percent of India's nickel resources. In Jharkhand, nickel is found with copper and uranium deposits.

Nickel is also manufactured as a by-product of copper mining in Ghatsila, Jharkhand, where nickel occurs with copper sulphide ore. The Ghatsila copper smelter is the only Indian foundry to produce LME grade nickel.

In India, nickel producing companies include Nicomet Industries, Sterlite Industries Limited, and Jhagadia Copper Limited.[116] HCL and MIDHANI have entered into a JV to produce value-added copper-nickel tubes.[117]

India's stainless-steel sector uses directly imported nickel waste and scrap. This scrap and other intermediary nickel materials (including sinters, rods, and unwrought nickel) account for the majority of India's nickel imports.

The country is likely to remain dependent on imports for nickel raw materials until its industry has access to commercially viable mining and processing technologies and practices.

Australia and India can examine opportunities for joint exploration and development of nickel sulphide and laterite deposits in India, in line with its forecast (increasing demand for nickel). India could encourage this form of cooperation by addressing structural barriers to mining exploration.

These include the need to consolidate fragmented mineral tenements and resolve long-standing tenement ownership issues that have arisen as a result of overlapping and unprocessed applications, particularly in some states, such as Odisha, Jharkhand, and Chhattisgarh.

Notes:

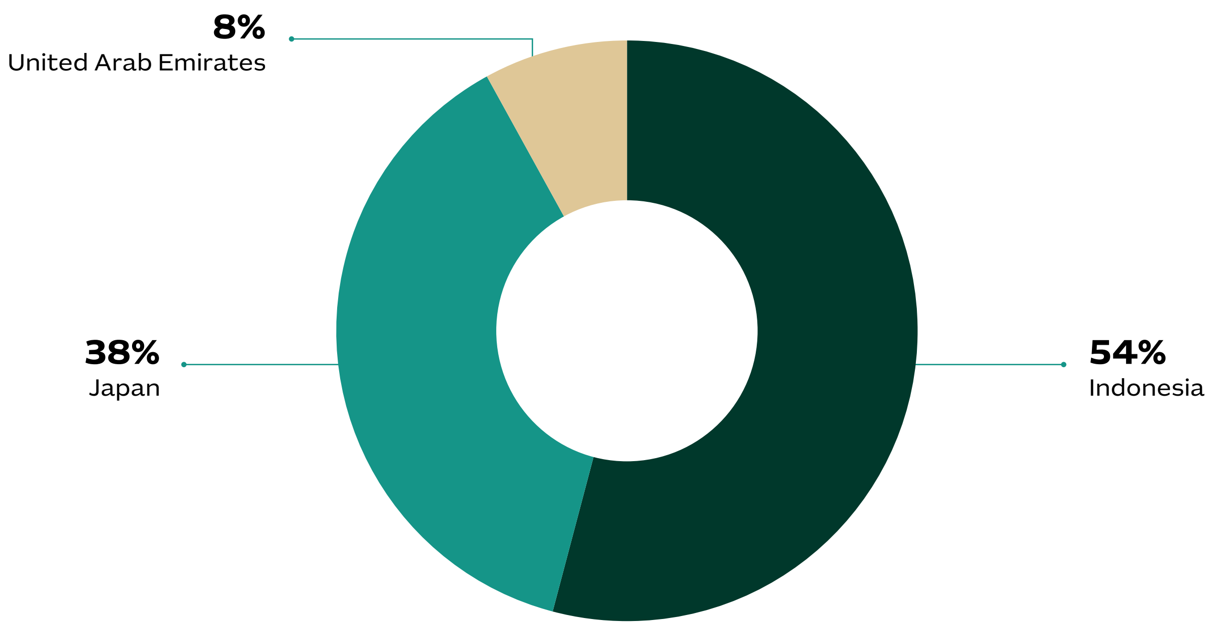
116. https://ibm.gov.in/writereaddata/files/06232020150332Nickel_2019.pdf
117. https://www.thehindubusinessline.com/companies/hcl-sees-a-copperbottomed-plan-in-nickel-alloy-tubes/article9827117.ece

Table 19: Indian imports of nickel and nickel products[118]

Import product description	HS code	2019		2020	
		Volume (kt)	Value (A$ million)	Volume (kt)	Value (A$ million)
Nickel ores and concentrates	2604	0.001	0.004	0.03	0.12
Nickel oxides and hydroxides	2825	0.1	12.8	0.4	8.4
Nickel chloride	2827	0.1	0.6	0.1	0.6
Nickel sulphate	2833	2	11	2.3	12.3
Ferro nickel	7202	123	558.9	39	195
Nickel mattes and sinters	7501	0.1	0.6	0.3	1.2
Nickel – unwrought	7502	32	659	30.2	609
Nickel – waste and scrap	7503	3.4	36.9	3.1	38
Nickel – powders and flakes	7504	0.3	12	0.3	9.9
Nickel – bars, rods, profiles, and wire	7505	4.3	141	4.6	125.7
Nickel – plates, sheets, strip, and foil	7506	3.6	126.8	4	143.5
Nickel – tubes, pipes, and their fittings	7507	1.6	63.7	1.6	55.47
Others	7508	0.6	41,6	0.3	37.86

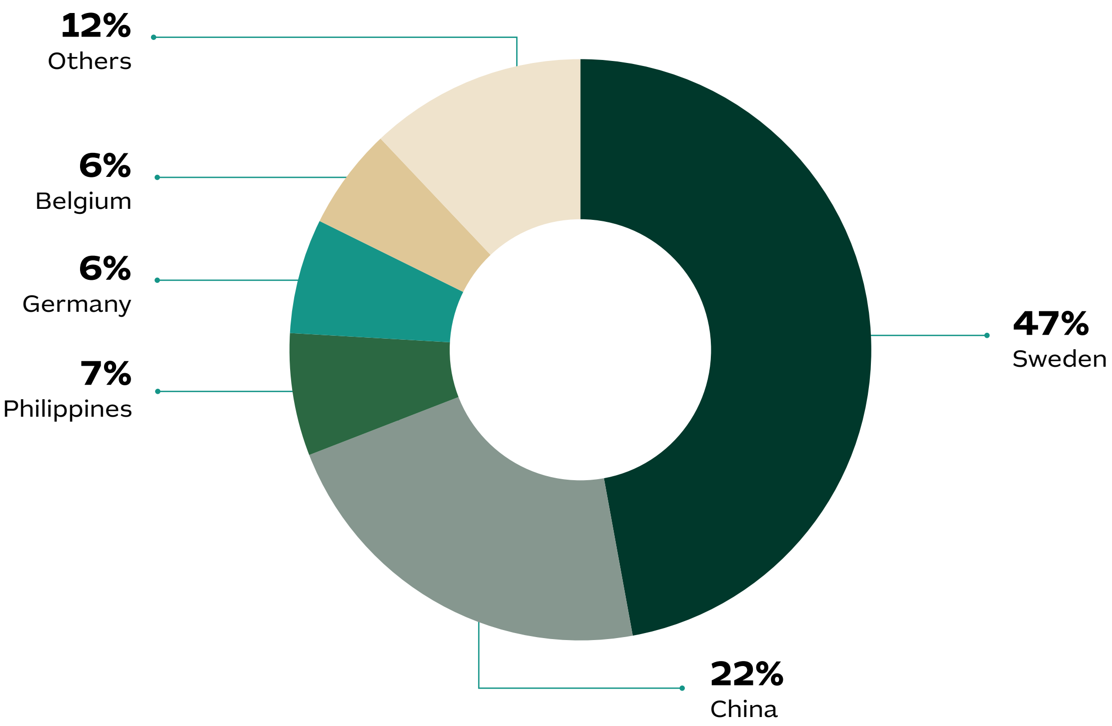
India imports the majority of its nickel ores and concentrates from Indonesia, Japan, and the UAE. Nickel oxides and hydroxides are imported from Sweden, China, the Philippines, Germany, Belgium, and Australia.

Figure 25: Imports (%) of nickel ores and concentrates in 2020[119]



Notes:
118. UN Comtrade, https://comtrade.un.org/
119. UN Comtrade, https://comtrade.un.org/

Figure 26: Imports (%) of nickel oxides and hydroxides in 2020[120]



The following table lists Indian government duties on imported nickel:

Table 20: Import duties on various nickel products from April 2021[121]

	HS code	BCD	SWS	IGST	Total duties
Nickel and nickel articles	7,501 to 7,508	5%	10%	18%	24.49%
Ferro nickel	7,202	2.5%	10%	18%	21.25%

Note: The IGST is applicable on both imports and Indian manufacture and is an eligible 'input tax credit', which can be offset against GST liability.

Australian supply capability

Australia has EDR of 21.2 Mt of contained nickel, ranking first in the world with 24 percent of the global nickel EDR. Australia produced 0.155 Mt of contained nickel in 2019, ranking sixth in terms of global production.

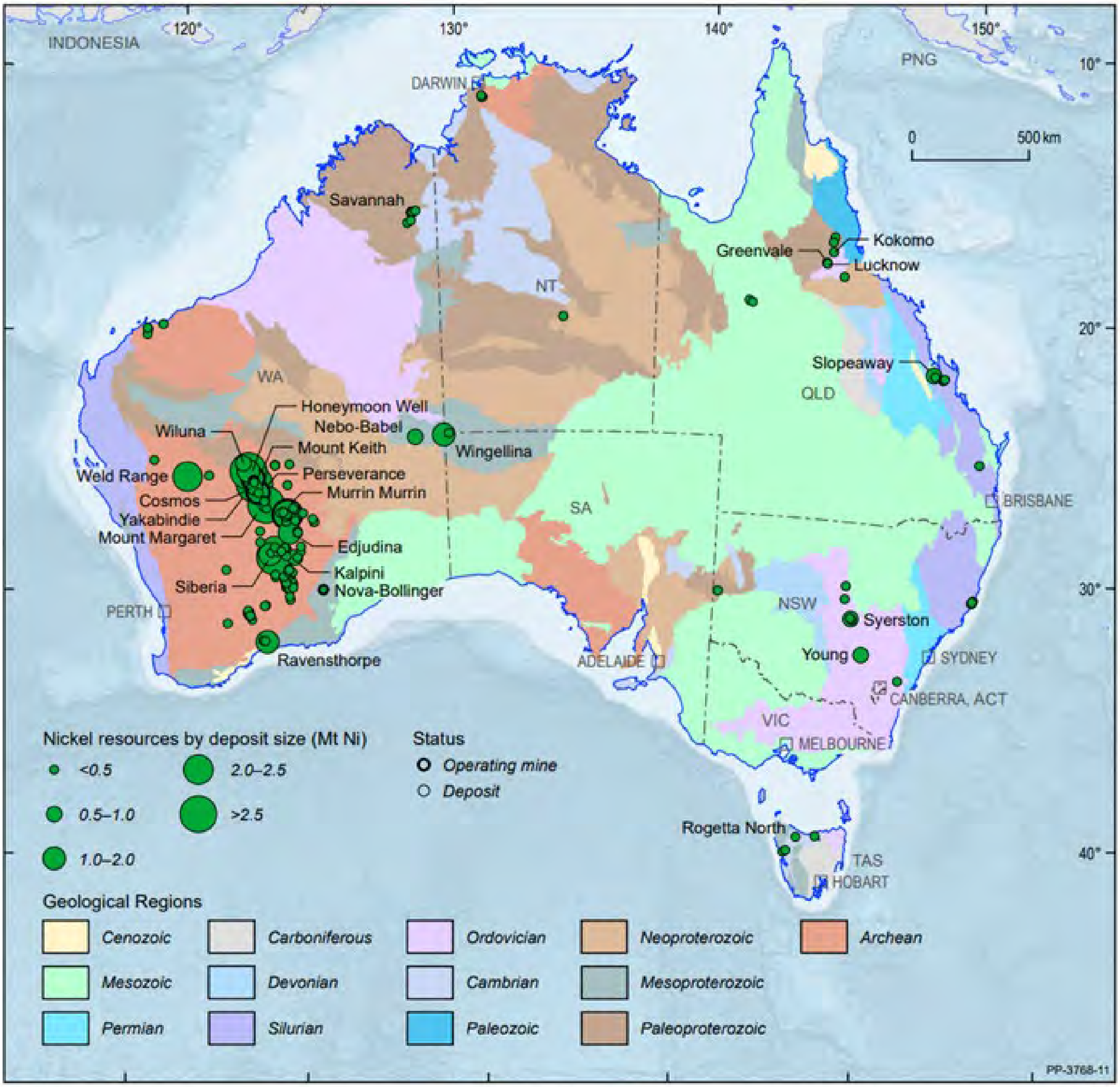
Current global demand for nickel is 2.7 Mt per year; this is expected to rise by a further 2.6 Mt by 2030.[122] Indonesia is the largest nickel producer, but Australia has the world's largest reserves and a large pipeline of early-stage nickel projects and nickel exploration prospects. Australia is expected to contribute more than 25 percent to the newly mined supply by 2030.[123]

Notes:

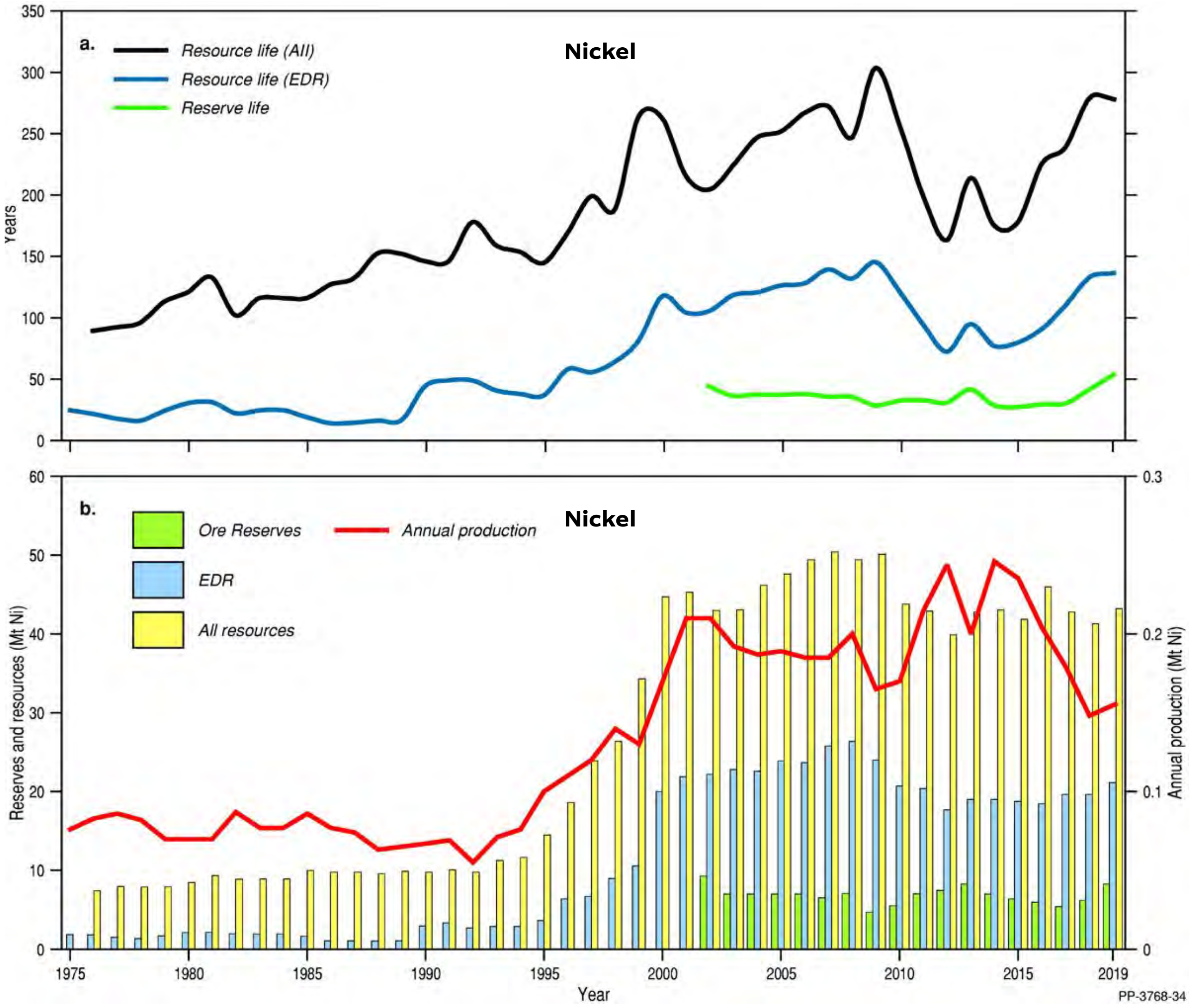
120. UN Comtrade, https://comtrade.un.org/
121. CBIC -Ministry of Commerce, Government of India reports
122. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC123439/roskill
123. https://www.nsenergybusiness.com/features/nickel-reserves-countries/

Some of the world's most significant komatiite-hosted nickel sulphide and lateritic deposits occur in Western Australia. In Australia, nickel exploration drives the development of other critical minerals. These include cobalt, platinum-group elements, and scandium.[124]

Figure 27: Australian nickel projects



Notes:
124. Australian Critical Minerals Prospectus 2020



Source: Geoscience Australia

Table 21 – Australia's Nickel Projects[125]

	Project name	Company	Project status	Mineral resource tonnage (Mt)	Actual/expected product	Prospective ancillary product
New South Wales	**Sunrise**	Sunrise Energy Metals Limited (formerly Clean TeQ Holdings Limited)	Pre-construction	160	Battery-grade nickel sulphate ($NiSO_4$-$6H_2O$)	Battery-grade cobalt sulphate ($CoSO_4$-$7H_2O$); scandium oxide (Sc_2O3); ammonium sulphate ($(NH_4)_2SO_4$)
	Nico Young	Jervois Mining Ltd	PFS	3.2	Battery-grade nickel sulphate ($NiSO_4$-$6H_2O$)	Cobalt sulphate crystals ($CoSO_4.7H_20$)
Queensland	**Sconi**	Australian Mines Ltd	FS	93.51	Battery-grade nickel sulphate ($NiSO_4$-$6H_2O$)	Cobalt sulphate crystals ($CoSO_4.7H_20$); high-purity scandium oxide (Sc_2O_3)
Western Australia	**Beta Hunt**	RNC Minerals Corp	Operating	0.561	Nickel-in-concentrate (2.64% Ni)	-
	Forrestania	Western Areas Ltd	Operating	18.18	Nickel-in-concentrate (14% Ni)	-
	Long Complex	Independence Group NL	Care and maintenance	0.035 Mt contained Ni	Nickel-in-concentrate	-
	Murrin Murrin	Glencore Plc	Operating	235.8	Nickel briquettes	Cobalt briquettes
	Nickel West	BHP Ltd	Operating	599	Nickel powder and briquettes; battery-grade nickel sulphate ($NiSO_4$-$6H_2O$)	-
	Savannah	Panoramic Resources Ltd	Operating	18.8	Nickel-in-concentrate	-
	Nova-Bollinger	Independence Group NL	Operating	11.8	Nickel-in-concentrate	-
	Honeymoon Well	PJSC MMC Norilsk Nickel	Developing	1.18 Mt contained Ni	Nickel-in-concentrate; potentially battery-grade nickel sulphate ($NiSO_4$ $6H_2O$)	-
	Lake Johnston	Poseidon Nickel Ltd	Care and maintenance	0.075 Mt contained Ni	Nickel-in-concentrate	-

Notes:
125. Geoscience Australia

	Project name	Company	Project status	Mineral resource tonnage (Mt)	Actual/expected product	Prospective ancillary product
	Lanfranchi	Black Mountain Metals LLC	Care and maintenance	0.099 Mt contained Ni	Nickel-in-concentrate	-
	North Kambalda	Mincor Resources NL	Care and maintenance	0.058 Mt contained Ni	Nickel-in-concentrate	-
	South Kambalda (Cassini)	Mincor Resources NL	Operating	5.20	Nickel-in-concentrate	-
	Ravensthorpe	First Quantum Minerals Ltd	Care and maintenance	326.1	Mixed nickel-cobalt hydroxide precipitate	-
	Cosmos	Western Areas Ltd	PFS	64.4	Battery-grade, high-purity nickel sulphate ($NiSO_4.6H_2O$)	-
	Goongarrie	Ardea Resources Ltd	PFS	259	Battery-grade, high-purity nickel sulphate ($NiSO_4.6H_2O$)	Battery-grade, high-purity cobalt sulphate ($CoSO_4.7H_2O$)
	West Musgrave (Nebo-Babel)	OZ Minerals Ltd	PFS	390	Mixed nickel-cobalt hydroxide precipitate	-
	Wingellina	Metals X Ltd	FS	182.6	Battery-grade nickel sulphate ($NiSO_4{\cdot}6H_2O$)	Cobalt sulphate crystals ($CoSO_4.7H_2O$)
	NiWest	GME Resources Limited	PFS	85.2	Nickel sulphate hexahydrate ($NiSO_4{\cdot}6H_2O$)	Cobalt sulphate heptahydrate ($CoSO_4{\cdot}7H_2O$)
	Mt Thirsty	Conico; Barra Resources	PFS	22.8	Nickel sulphate ($NiSO_4.6H_2O$)	Manganese; cobalt
Tasmania	**Barnes Hill**	NQ Minerals Plc	PFS	9.54	22.2% nickel sulphate ($NiSO_4.6H_2O$)	17.7% cobalt carbonate ($CoCO_3$); 35.2% manganese carbonate ($MnCO_2$)

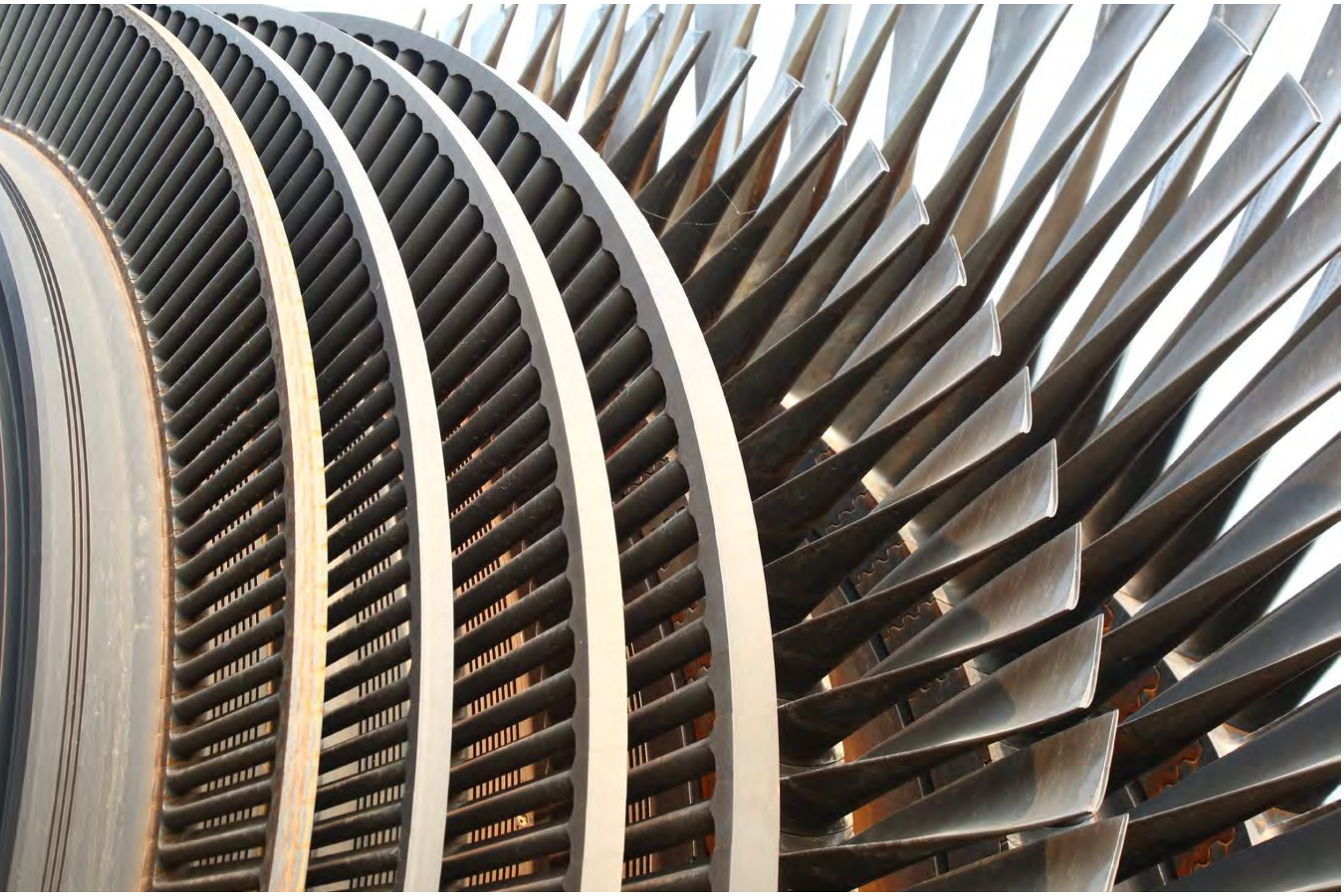
Potential project cooperation opportunities

India's nickel demand is currently driven by the stainless steel sector, which uses iron-chrome-nickel alloy. High-performance lithium-ion batteries require high-grade nickel inputs, such as nickel metal, nickel hydroxide, or nickel sulphate.

Australian nickel miners can use this potential growth opportunity through strategic alliances with Indian companies.

Key opportunities

- Australian nickel suppliers could explore offtake opportunities with traditional sectors, such as steel, electrodes, engineering, and defence, in India.
- Advanced Australian nickel and nickel-cobalt development projects are seeking funding for project construction. This presents an opportunity to involve Indian battery and EV manufacturers, and international battery technology partners, as strategic investment and offtake partners in the development of Australian nickel and nickel-cobalt projects.
- A number of Australian cobalt development projects are nickel-cobalt laterite projects. Participation in these would enable Indian companies and conglomerates to establish secure supplies of cobalt.
- Australian companies could partner with Indian conglomerates with diversified interests to explore investment in Australian nickel projects and processing units.
- India could encourage increased exploration and development of nickel sulphide and laterite deposits, including by addressing structural issues that restrict mining exploration.
- Australian and Indian organisations could explore collaborative research on battery technologies to evaluate nickel as a viable substitute in battery chemistries and support resilient supply chains.



Ilmenite and rutile

Ilmenite and rutile are the most common titanium minerals. Demand for titanium minerals is driven by the increasing trends of urbanisation and industrialisation. More than 90 percent of ilmenite and rutile are used to produce titanium dioxide, which has applications in the chemicals, paint, and pigment industries.[126]

Sectors such as aerospace, general engineering, atomic energy, and power generation are other end-use industries with modest demand for titanium metal and alloys.

Synthetic rutile has applications in welding electrodes, a sector that in India is dominated by SMEs. This sector accounts for almost all of the demand for rutile in India.[127]

India has established midstream and downstream titanium manufacturing capability for products such as titanium dioxide and titanium sponge.

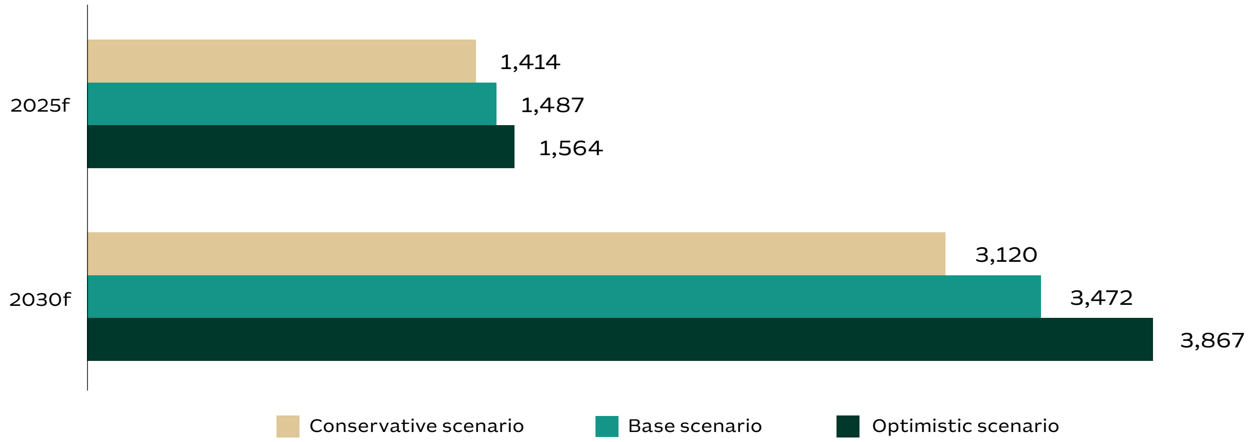
India could enhance its titanium value chain through strategic investments and partnerships for mining and by increasing its capabilities in the intermediate and downstream titanium value chain.

Australia is one of the largest suppliers of high-grade titanium bearing minerals to India. It has extensive titanium resources to cater to current and future demand from Indian industries.

Indian market analysis

The Indian ilmenite market was estimated at 180 kt in 2020. It is expected to reach a cumulative demand potential of 2,833-3,512 kt by 2030. Furthermore, the Indian rutile market was estimated to be 12 kt in 2020. It is expected to reach a cumulative demand potential of 287-355 kt by 2030.[128]

Figure 28: Cumulative Indian market demand potential for titanium-bearing minerals[129]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	1,564	1,487	1,414	3,867	3,472	3,120

Disclaimer: The demand potential identified shall be subject to the expected development of manufacturing competence in India

Notes:

126. Mineral Yearbook 2019 (Part II – Metal and Alloys) – 58th edition – Ilmenite and Rutile- Advance Release – Indian Bureau of Mines
127. Mineral Yearbook 2019 (Part II – Metal and Alloys) – 58th edition – Ilmenite and Rutile- Advance Release – Indian Bureau of Mines
128. Analysis based on information publicly available in following government and other reports - IREL sources and UNCOMTRADE.
129. Analysis based on information publicly available in following government and other reports - IREL sources and UNCOMTRADE

The following table shows that each end use segment's share of titanium bearing mineral consumption is likely to be constant from 2020 to 2030.

Table 22: Indian titanium bearing mineral market forecast by end-use segment by volume[130]

	End-use segment	2020	2025f	2030f
Ilmenite	Chemicals, pigments, and paint	99%	99%	99%
	Electrodes	<1%	<1%	<1%
	Others (including ceramics, ferroalloys, pulp, and paper)	<1%	<1%	<1%
Rutile	Electrodes	100%	100%	100%

Key industry participants

There are multiple large players in the downstream value chain for ilmenite in India. However, few have capabilities to produce titanium slag, synthetic rutile, titanium sponge, and titanium metal and alloy.

India's industrial self-sufficiency programmes aim to increase domestic manufacturing and infrastructure development. Atmanirbhar Bharat has a focus on the defence and aerospace sectors and will likely increase India's demand for ilmenite.

Table 23: Potential target technologies and manufacturers[131]

End-use segment	Technology / product	End-use industry	Key raw material[132]	Key industry players	Key geographical locations
Chemicals, pigments, and paint	**Titanium dioxide**	Pigments, ceramics, paints and coatings	Titanium dioxide	*Key players in the intermediate value chain* Travancore Titanium Products Limited, Kerala Minerals and Metals Limited (KMML), DCW Limited, V.V. Mineral, and Beach Minerals Company *Key players in the downstream value chain** Berger Paints, Asian Paints, Kansai Nerolac Paints, Nippon Paint Gujarat Alkalies and Chemicals Limited, India Glycols Limited, AkzoNobel	Titanium dioxide manufacturing clusters are in Tamil Nadu, Kerala, and Andhra Pradesh in the south; and Odisha is in the east

*https://www.business-standard.com/article/specials/the-tio2-factor-197091001156_1.html ; https://www.bergerpaints.com/ ; https://www.asianpaints.com

Notes:

130. Indian Mineral Yearbook 2019 (Part II – Metal and Alloys) – 58th edition – Ilmenite and Rutile- Advance Release

131. Secondary research and Industry sources

132. http://www.supraalloys.com/titanium-grades.php

End-use segment	Technology / product	End-use industry	Key raw material[132]	Key industry players	Key geographical locations
Defence, aerospace, and space	**Fastening elements, airframes, landing gear, liquid propellant tanks**	Defence vehicles, aerospace	Titanium sponge, titanium metal, titanium 6AL-4, aerospace-grade alloys	MIDHANI, KMML, Bharat Dynamics Limited, Boeing India Private Limited, Indian Space Research Organisation, Kalyani Group	Aerospace hubs in Bangalore, Belgaum, Ramanagara, Shimoga, Dharwad and Kolar, all in Karnataka
Ferro alloys	**Transformers, dynamos, iron, steel, automobile valves**	Steel, automotive parts, machinery	Ferro titanium, other alloy-grade titanium	*Key players in the intermediate value chain* Essel Mining and Industries Limited, Facor Alloys Limited, Jindal Steel and Power Limited, IDCOL Ferro Chrome and Alloys Limited, Des Raj Bansal Group	Ferroalloy hubs in Chhattisgarh, Gujarat and Odisha
Automotive	**Automotive springs, engine connecting rods**	Automotive	Ferro titanium and grade 2 titanium	*Key players in the downstream value chain** Tata Motors, Maruti Suzuki, Hero MotoCorp Limited, Hyundai Motors, Kia Motors, Toyota Motors, Bajaj Motors	Major automotive manufacturing clusters are in Gurugram in Delhi; Mumbai, Pune and Nashik in Maharashtra; Chennai in Tamil Nadu; Jamshedpur In Jharkhand; Anantapur in Andhra Pradesh; and Rajkot and Halol in Gujarat

*https://www.marutisuzuki.com, https://www.tkap.com/,https://tataautocomp.com/thsl/products/

Supply scenario in India

Titanium is the fourth most abundant metal globally. It is mainly found in ilmenite (50–65 percent titanium dioxide) and rutile (95 percent titanium dioxide). The most common deposits of titanium are heavy mineral sand deposits containing ilmenite, rutile, and leucoxene (an alteration mineral).

Processed titanium metal accounts for 5 percent of the total titanium mineral consumption, with the remainder used in the pigment industry. Pigments are produced using either a sulphate or carbochlorination process that converts titanium dioxide into titanium chloride.

Global resources of ilmenite in 2019 were 800 Mt and that of Rutile were 55Mt.[133] Major economic resources are found in Australia (32 per cent), China (30 per cent), India (11 percent), Brazil (6 per cent), South Africa (5 per cent), Norway (5 per cent), Canada (4 per cent), Mozambique (2 per cent) and Madagascar (1 per cent).

World economic resources of rutile are estimated at 47 Mt that contain titanium. Major economic resources of rutile are found in Australia (62 percent), India (16 percent), South Africa (13 percent), and Ukraine (5 percent).[134]

In 2018, major global producers of ilmenite concentrate were Canada (23 percent), China (16 percent), Mozambique (11 percent), Ukraine (8 percent), Norway (7 percent), India (7 percent), and South Africa (6 percent). Key producers of rutile concentrate were Australia (29 percent), Ukraine (15 percent), and Kenya (14 percent).[135] However, Australia ranks 3 amongst the largest ilmenite producers of the world in 2020.[136]

Indian ilmenite reserves were estimated at 265 Mt in 2019, while rutile reserves were 11 Mt.[137] India has 11 percent of the world's titanium-bearing minerals. However, it accounted for 1 percent of the installed global production capacity and currently meets most of its demand through imports.

In 2020, India imported most of its titanium concentrate from Mozambique (62 percent), Australia (12 percent), China (9 percent), South Africa (3 percent), and Thailand (3 percent). It imported most of its titanium oxide and dioxide from China (41 percent) and South Korea (33 percent). Imports of titanium and alloys (including waste and scrap) were mainly sourced from the US (26 percent), China (18 percent), Japan (13 percent), and Singapore (8 percent).[138]

India's upstream value chain for titanium – ilmenite, rutile, and leucoxene mineral sands mining – is dominated by two major state-owned enterprises: IREL (India) Limited and KMML.

In the intermediate value chain, KMML produces titanium dioxide, nano titanium dioxide pigment (rutile), titanium tetrachloride, and titanium sponge. Travancore Titanium Products Limited produces anatase- and rutile-grade titanium dioxide.

DCW Limited and Cochin Minerals and Rutile Limited produce beneficiated ilmenite (synthetic rutile) used for pigment manufacturing and welding electrodes, and as feedstock for titanium sponge manufacturing.

KMML is India's only producer of titanium sponge, with production of 500 tonnes per year. UKTMP JSC, a titanium sponge and metals producer in Kazakhstan, signed a MOU with IREL to collaborate in the titanium value chain and produce titanium slag in India.[139]

MIDHANI manufactures superalloys and titanium alloys for materials and components, adding downstream value. In 2021, MIDHANI and Hindustan Aeronautics Limited signed a MOU to produce composite raw materials for applications in the aircraft industry.[140]

India's titanium dioxide pigments and paint industries depend on titanium dioxide feedstock. Indian producers usually import pigments, mainly from China and South Korea, but also from Australia.

Notes:

133. Geoscience Australia
134. Mineral Yearbook 2019 (Part II – Metal and Alloys) – 58th edition – Ilmenite and Rutile- Advance Release – Indian Bureau of Mines
135. Mineral Yearbook 2019 (Part II – Metal and Alloys) – 58th edition – Ilmenite and Rutile- Advance Release – Indian Bureau of Mines
136. Geoscience Australia
137. Mineral Yearbook 2019 (Part II – Metal and Alloys) – 58th edition – Ilmenite and Rutile- Advance Release – Indian Bureau of Mines
138. UN Comtrade, https://comtrade.un.org/
139. https://psuwatch.com/irel-signs-mou-with-uktmp-jsc-kazakhstan-for-production-of-titanium-slag
140. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1695265

Australian titanium dioxide pigment manufacturing companies could explore strategic partnerships with key Indian paint manufacturers to supply products for the carbochlorination process to the industry.

Companies from the two countries could collaborate to develop the titanium value chain and address India's increasing demand for value-added segments, such as titanium sponge, metal, and alloy manufacturing for high-value sectors (including aerospace and defence).

Table 24: Indian imports of titanium[141]

Import product description	HS code	2019		2020	
		Volume (kt)	Value (A$ million)	Volume (kt)	Value (A$ million)
Titanium ores and concentrates	2614	146	88	87	61
Titanium oxides	2823	16	65	12	47
Titanium articles including waste and scrap	8108	8.5	162	8.1	104

Table 25: Import duties on titanium products from April 2021[142]

	HS code	BCD	SWS	IGST	Total duties
Titanium dioxide	2605	10%	10%	18%	30.98%
Titanium products (including waste and scrap)	8108	5%	10%	18%	24.49%
Titanium oxides	2823	10%	10%	18%	30.98%
Titanium ores and concentrates	2614	5%	10%	18%	24.49%
Pearlescent pigments (titanium dioxide, coated micananeous and lustres pearl pigment)	3606	10%	10%	18%	30.98%

Note: The IGST is applicable on both imports and Indian manufacture and is an eligible 'input tax credit', which can be offset against GST liability.

Notes:

141. UN Comtrade, https://comtrade.un.org/

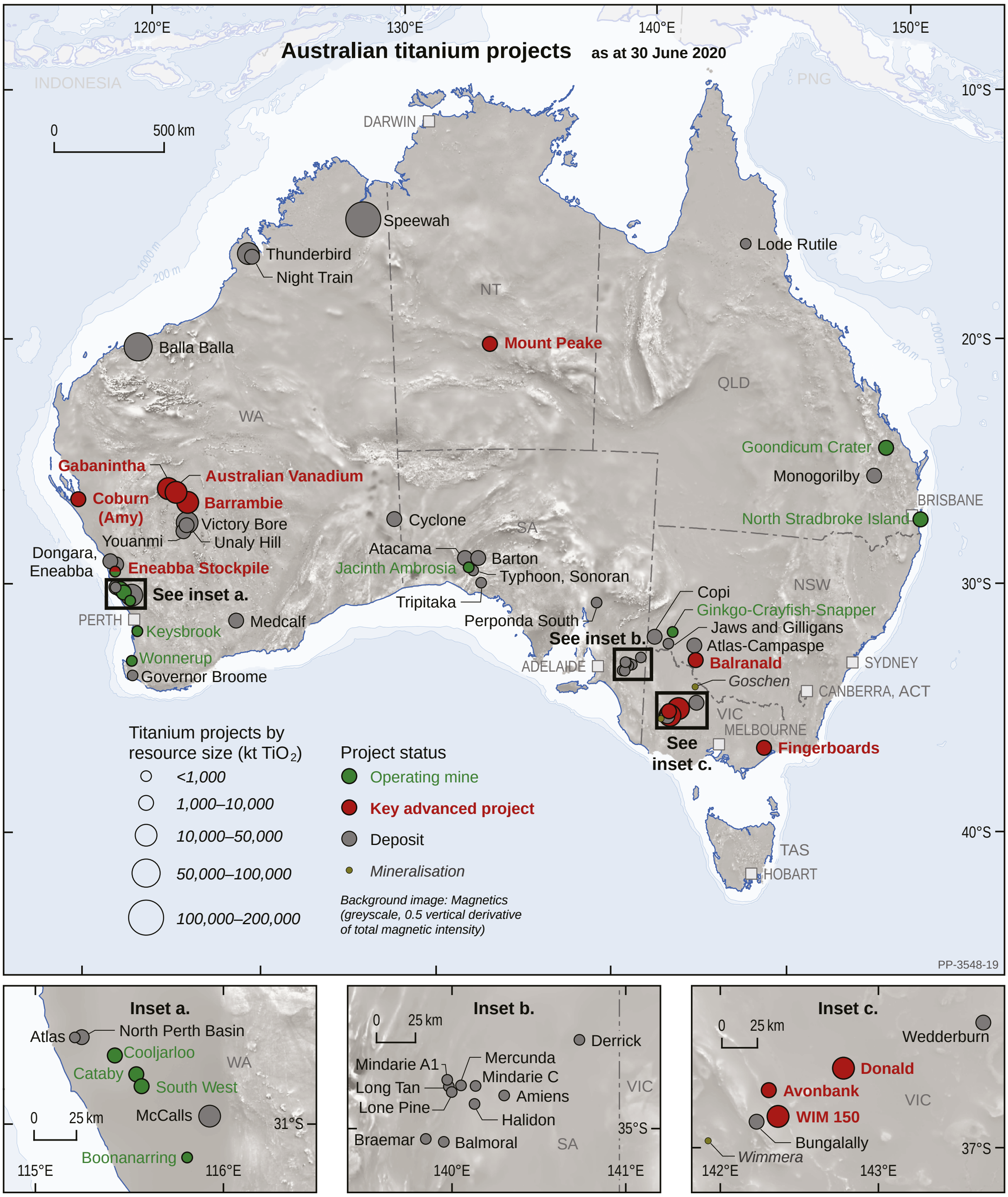
142. CBIC - Ministry of Commerce, GOI

Australian supply capability

Australian heavy mineral sands deposits hold economic resources of 276 Mt of ilmenite and 35 Mt of contained rutile, ranking second and first in the world, respectively.

The country produced 1.4 Mt of ilmenite and 0.2 Mt of rutile in 2019, ranking fourth and first respectively, for global production by country.[143]

Figure 29: Australian titanium projects



Source: Australian Critical Minerals Prospectus 2020

Notes:

143. Geoscience Australia, https://www.ga.gov.au/scientific-topics/minerals/mineral-resources-and-advice/australian-resource-reviews/minerals-sands

The following table shows Australia's operating mines and a robust project pipeline to meet future titanium requirements.

Table 26: Australia's advanced titanium minerals projects

Critical mineral	Project name	Company	Project status	Primary mineral(s)	Tonnage (Mt)	Grade	Units		Contained (kt)
Titanium	**Cataby**	Iluka Resources Ltd	Operating	Ti, Zr	308.0	1.75	%	TiO_2	5,394
Titanium	**Goondicum Crater**	Melior Resources Inc	Operating	Ti,P	92.8	5.20	%	TiO_2	4,828
Titanium	**Cooljarloo**	Tronox Holdings Plc	Operating	Ti, Zr	416.0	0.79	%	TiO_2	3,299
Titanium	**South West**	Iluka Resources Ltd	Operating	Ti, Zr	83.0	3.96	%	TiO_2	3,289
Titanium	**Keysbrook**	Doral Pty Ltd	Operating	Ti, Zr	78.2	1.26	%	TiO_2	982
Titanium	**Jacinth Ambrosia**	Iluka Resources Ltd	Operating	Zr, Ti	184.0	0.47	%	TiO_2	866
Titanium	**Ginkgo-Crayfish -Snapper**	Tronox Holdings Plc	Operating	Ti, Zr (REE)	74.0	1.06	%	TiO_2	783
Titanium	**Boonanarring**	Image Resources Ltd	Operating	Ti, Zr	30.3	1.98	%	TiO_2	601
Titanium	**Wonnerup**	Tronox Holdings Plc	Operating	Ti, Zr	21.0	2.63	%	TiO_2	552
Titanium	**Eneabba Stockpile**	Iluka Resources Ltd	Operating	Zr, REE, Ti	1.0	16.92	%	TiO_2	169
Titanium	**North Stradbroke**	Sibelco Australia Ltd	Operating	Ti, Zr					NA
Titanium	**Atlas-Campaspe**	Tronox Holdings Plc	Construction	Ti, Zr	88.0	3.16	%	TiO_2	2,785
Titanium	**Balla Balla**	BBI Group Pty Ltd	FS	V, Ti	455.9	13.80	%	TiO_2	62,914
Titanium	**Donald**	Astron Ltd	FS	Zr, Ti, REE	2,427.0	1.98	%	TiO_2	47,996
Titanium	**Thunderbird**	Sheffield Resources Ltd	FS	Zr, Ti	3,230.0	1.45	%	TiO_2	46,893
Titanium	**Barrambie**	Neometals Ltd	FS	Ti, V	280.1	9.18	%	TiO_2	25,713
Titanium	**WIM150**	Murray Zircon Pty Ltd	FS	Zr, Ti, REE	1,650.0	1.29	%	TiO_2	21,218
Titanium	**Fingerboards**	Kalbar Resources Ltd	FS	Zr, Ti, REE	530.0	1.60		TiO_2	8,689
Titanium	**Mount Peake**	TNG Ltd	FS	V, Ti, Fe	160.0	5.30	%	TiO_2	8,480
Titanium	**Coburn (Amy)**	Strandline Resources Ltd	FS	Ti, Zr	1,606.0	0.48	%	TiO_2	7,693
Titanium	**Balranald**	Iluka Resources Ltd	FS	Ti, Zr	45.5	15.68	%	TiO_2	7,136
Titanium	**Cyclone**	Diatreme Resources Ltd	FS	Zr, Ti	203.0	0.73	%	TiO_2	1,488
Titanium	**Dongara**	Tronox Holdings Plc	FS	Ti, Zr	68.0	1.91	%	TiO_2	1,297
Titanium	**Atlas**	Image Resources Ltd	FS	Ti, Zr	18.1	2.23	%	TiO_2	404
Titanium	**Mindarie C**	Murray Zircon Pty Ltd	Care and maint	Ti, Zr	19.3	1.28	%	TiO_2	246
Titanium	**Mindarie A1**	Murray Zircon Pty Ltd	Care and maint	Ti, Zr	8.8	1.20	%	TiO_2	105

Critical mineral	Project name	Company	Project status	Primary mineral(s)	Tonnage (Mt)	Grade	Units		Contained (kt)
Titanium	**Australian Vanadium**	Australian Vanadium Ltd	FS	V, Ti	208.2	9.00	%	TiO_2	18,738
Titanium	**Avonbank**	WIM Resource Pty Ltd	FS	Zr, Ti	490.0	1.54	%	TiO_2	7,534
Titanium	**Medcalf**	Audalia Resources Ltd	FS	V, Ti	32.0	8.98	%	TiO_2	2,874
Titanium	**Copi**	Relentless Resources Ltd	PFS	Ti, Zr	75.4	1.79	%	TiO_2	1,353

Source: Australian Critical Minerals Prospectus 2020

In addition to the above list of advanced titanium projects, Australia has a number of projects in early stages (with pre-feasibility studies underway) that are seeking investment.[144]

Australia has two types of titanium deposits: heavy mineral sands deposits (by far the most common) and titanium-vanadium deposits in igneous hard rock.

Australian heavy mineral sands deposits commonly contain titanium minerals (ilmenite, rutile, anatase, and leucoxene), zirconium, and rare earth oxides (monazite and xenotime). Therefore, by investing in one Australian heavy mineral sands project, an Indian company could secure supplies of titanium, zirconium, and REEs.

Similarly, by investing in one Australian igneous hard rock titanium-vanadium project, an Indian company could secure supplies of both titanium and vanadium.

Potential project cooperation opportunities

Australian companies could be alternative sources of ilmenite and rutile for the Indian industry. Australian project proponents can explore collaborative models to gain a significant market share and assist Indian customers to adjust their processing capabilities in line with the qualities of Australian ilmenite and rutile.

Australian titanium dioxide pigment manufacturing companies could explore giving prominent Indian paint manufacturing players preferential long-term supply contracts for carbochlorination processes for pigments.

This partnership could be elevated to jointly develop an intermediate value chain for titanium and establish a global manufacturing hub for the titanium sponge and titanium metal and alloy used in aerospace and defence applications. Australian and Indian companies could examine setting up mutually beneficial engagement models for a supply chain to address global need.

Key opportunities

- Australian projects could explore offtake arrangements with Indian companies in traditional sectors, such as paint, pigments, ceramics, steel, and automotive manufacturing. Key factors to consider include technical specifications, volumes, and prices.
- Australian companies could assess Indian customers' interest in forming strategic partnerships, including their interest in investing to develop mineral assets in Australia. This could include Australian heavy mineral sands projects with high titanium content, and Australian igneous hard rock titanium-vanadium projects.
- Companies could collaborate to manufacture titanium dioxide pigment in India using ilmenite concentrates sourced from Australian mineral sands mines.
- Australian organisations could explore conducting joint research with Indian defence organisations to develop bespoke aerospace-grade alloys.
- Australian METS companies could engage with Indian companies in the intermediate value chain to support processing technology upgrades, expand their capacity to add value in India, and achieve cost competitiveness.

Notes:
144. Australian Critical Minerals Prospectus 2020

Light rare earths

Amongst 16 rare earth elements (REEs), critical minerals that are light rare earths (LREEs) include neodymium, praseodymium, lanthanum, cerium, and samarium. Of these, the most commonly used are neodymium and praseodymium (NdPr). NdPr is widely used for manufacturing neodymium iron boron (NdFeB) magnets. India depends on imports for all its NdFeB magnets.

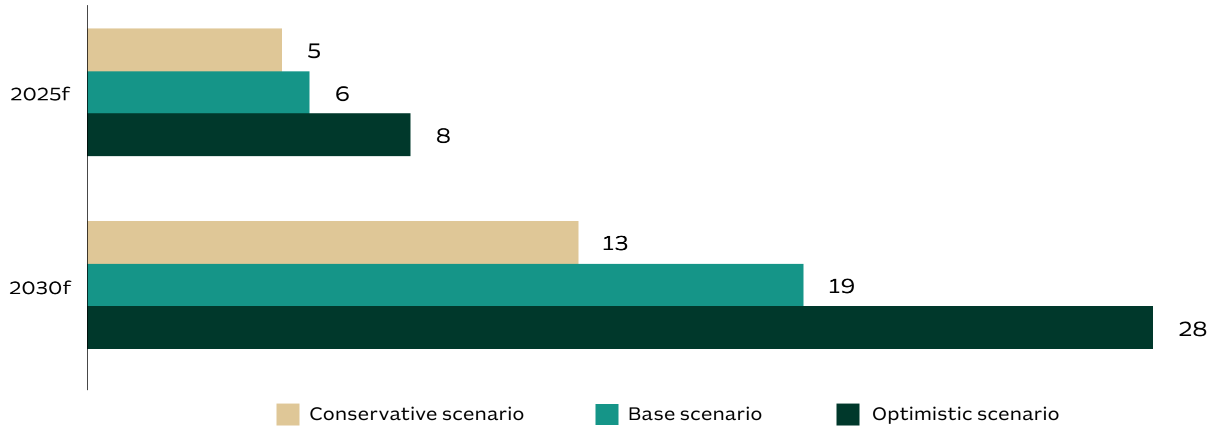
Demand for these magnets will be driven by increasing wind power capacity and demand for EVs in India. Samarium is also important because it is used to manufacture samarium cobalt (SmCo) magnets. It is also used in industrial pumps, and the defence, automotive and aerospace sectors.

Indian market analysis

1. Neodymium and praseodymium

The NdPr oxide market was estimated at 1.1 kt in 2020. It is forecast to grow to about 18.6 kt by 2030.[145]

Figure 30: Cumulative Indian market demand potential for NdPr (kt)[146]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	8	6	5	28	19	13

Disclaimer: The demand potential identified shall be subject to the expected development of manufacturing competence in India

NdPr elements are used to manufacture bonded and sintered NdFeB magnets. These magnets have significant applications in EV traction motors and wind turbines. They also have multiple industrial applications, such as in brushless DC motors, magnetic pulleys, separators, and chucks. NdPr content in these NdFeB magnets is about 30 percent metal (from NdPr oxide).[147]

Over the next decade, EVs and wind turbines are likely to drive most demand for NdPr. The quantity of NdFeB magnets used in EVs varies from 350g to 2 kg per vehicle.[148] As 30 percent of these magnets (by weight) are NdPr, demand for NdPr for EVs is expected to reach 6–12 kt by 2030, provided these magnets are produced in India.

Notes:

145. Based on demand of NdFeB magnets in the field of EVs, wind turbine and other sectors.

146. Analysis based on information available in following reports- NITI Aayog: India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey: The unexpected trip: The future of mobility in India beyond COVID-19; By 2024, nearly half of new 3-wheelers sold will be e-autos, CRISIL; Electric Vehicle EV -Charging towards a bright future, Avendus, July 2020; and ICRA press release 2020, Global Wind Energy Council- India Wind Outlook towards 2022; UN Comtrade Permanent Magnets Import Export Data. *While 2020 represents actual consumption for the year based on imports, 2025 and 2030 represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.

147. https://www.arultd.com/products.html

148. Role of substitution in mitigating the supply pressure of rare earths in electric road transport applications - ScienceDirect

NdPr is also essential in wind turbines. India had 38.8 GW of the installed capacity of wind power in 2020.[149] The country's estimated capacity will reach 140 GW by 2030, at a CAGR of 13 percent.[150] Vestas, Siemens Gamesa, and ReGen Powertech have about 60 percent market share of the equipment (which uses NdFeB magnet technology) for generating wind energy in India.[151,152] The requirement for 30 percent NdPr in these magnets means demand for NdPr for wind turbines is expected to reach 3–11 kt by 2030. [153]

NdFeB magnets are also used in other applications, including electronics and industrial magnetic equipment. Demand for NdPr for these applications was estimated at 0.9 kt in 2020 and is expected to reach 4 kt by 2030.

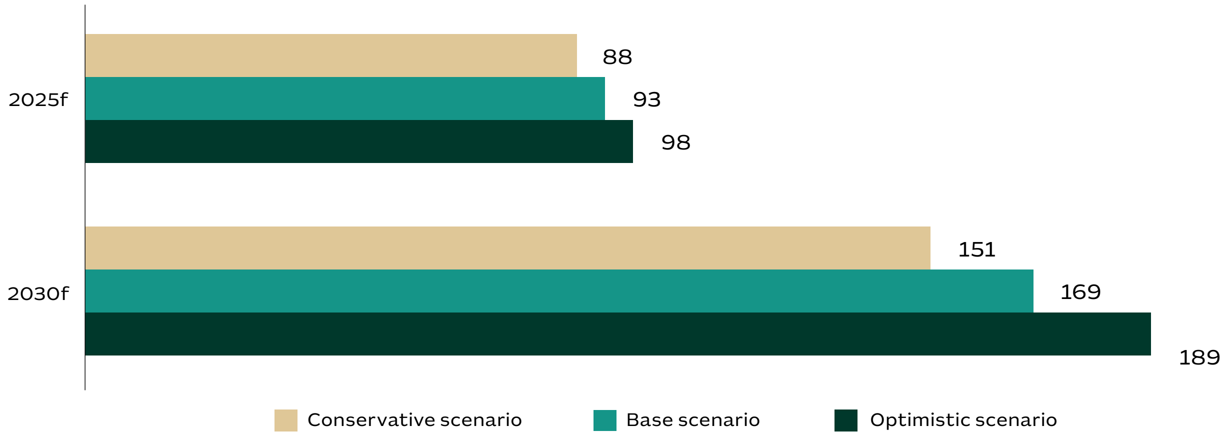
2. Samarium

Samarium reserves are estimated to be about 2 Mt globally, with only 700 tonnes being extracted worldwide each year.[154] India has total monazite reserves of 6.9 Mt, consisting of about 172 kt (2.5%) of samarium.[155, 156]

Samarium is needed to produce Samarium Cobalt (SmCo) magnets, which consist of 36 percent samarium and 64 percent cobalt. Due to the presence of cobalt, SmCo magnets can be more expensive than NdFeB magnets.[157]

IREL has a project underway in India to set up a 3,000 kg SmCo magnet manufacturing facility, using the entire rare earth supply chain.[158] By 2020, India had capacity to produce 160 tonnes of samarium and gadolinium compounds, while demand was only 2–3 tonnes.[159,160] Cumulative demand for samarium in India is expected to reach 151-189 tonnes by 2030. [161]

Figure 31: Cumulative Indian demand potential for samarium (tonnes)[162]



Notes:
149. MNRE-Physical Progress-28-02-2021
150. Global Wind Energy Council- India Wind Outlook towards 2022
151. https://about.bnef.com/blog/indias-top-wind-suppliers-in-2019/
152. https://about.bnef.com/blog/indias-top-wind-suppliers-in-2019/#:~:text=The%20top%20two%20turbine%20makers,together%20grabbed%2047%25%20market%20share.
153. Based on NdFeB requirement in manufacturing of wind turbine and demand of wind turbine by 2030
154. https://mmta.co.uk/metals/sm/
155. https://asia.nikkei.com/Economy/Trade-war/India-scrambles-to-look-overseas-for-rare-earths-used-in-EVs
156. IREL_PDAC_2014
157. https://www.first4magnets.com/tech-centre-i61/information-and-articles-i70/samarium-cobalt-magnet-information-i85/what-are-samarium-cobalt-magnets
158. https://www.irel.co.in/projects-under-implementation
159. Industry Resources
160. Industry Resources
161. Industry Resources
162. Estimated based on import data of permanent magnets from UN Comtrade. *The import of NdFeB magnets is expected to be 15% of India's total permanent magnets import. The trend is estimated based on the import trend of permanent magnets from 2015 to 2020.

	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	98	93	88	189	169	151

Disclaimer: The demand potential identified shall be subject to the expected development of manufacturing competence in India

3. Lanthanum and cerium

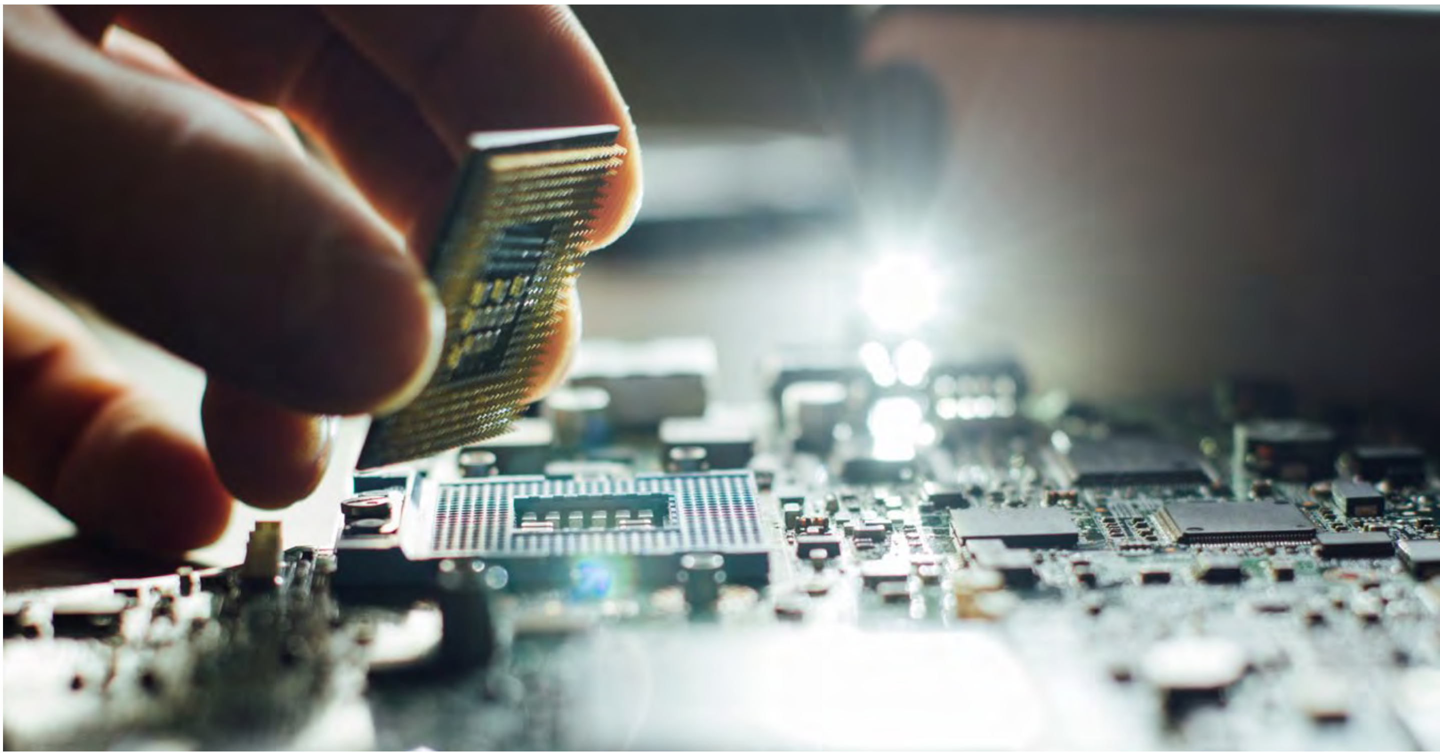
Lanthanum and cerium oxides are produced while processing rare earth oxides and have limited end-use applications. Many companies are exploring innovative commercial applications.

In 2020, India's domestic production capacity was 900–950 tonnes of lanthanum compound, while there was demand for only 10–15 tonnes.[163] Cerium production capacity was about 1,900–2,000 tonnes in 2020, while demand was at about 250–300 tonnes.

Prices for magnetic REEs, such as NdPr, will increase significantly, and supplies will become increasingly scarce after 2025. Adoption of cerium- and lanthanum-bearing NdFeB magnets is expected to accelerate, partially helping to offset the market's increasing under-supply of neodymium oxide.

Multiple projects to substitute neodymium and praseodymium with lanthanum and cerium in NdFeB magnets are currently underway. Some lanthanum and cerium mischmetal may soon be added to magnets to reduce the neodymium content without changing the magnets' properties and performance.

This will help increase demand for lanthanum and cerium. Toyota Corporation has developed the world's first magnet with 50 percent less neodymium (replacing it with lanthanum and cerium), while retaining heat-resistant properties.[164]



Notes:
163. Industry Resources
164. https://global.toyota/en/newsroom/corporate/21139684.html

Key industry participants

India's demand for NdFeB magnets is expected to rise substantially by 2030. This will lead to increased demand for NdPr.

Due to technology gaps, restricted availability of raw material that are not radioactive, and limited participation from the private sector, India depends on imported NdFeB magnets, mainly from China and Japan.

Developing an intermediate rare earth value chain (that is, converting rare earth concentrates into rare earth oxides, and metal and alloys) would help India reduce its dependency on imports. The Indian Government is working towards setting up a complete value chain for manufacturing NdFeB magnets. The issues of radioactivity for concentrate transportation, processing and waste usage or disposal need to be addressed.

IREL has entered into a MOU with Bhabha Atomic Research Centre (BARC), the Defence Metallurgical Research Laboratory, and ARCI to manufacture rare earth permanent magnets. BARC has developed technology to produce rare earth phosphors. However, these products do not yet have commercial applications.[165]

In December 2015, IREL signed a sales purchase agreement with Toyota Corporation and its subsidiary Toyotsu Rare Earths India Private Limited, to supply rare earth chloride. This is being produced at IREL's monazite processing plant at its Orissa Sands Complex.[166]

In October 2020, IREL released an expression of interest for setting up NdFeB magnet manufacturing units in India. IREL proposes to provide raw materials.[167]

Key importers or buyers of imported magnets include the following:

- Permanent Magnets Limited
- Dura Magnets Private Limited
- MAHLE.

Prominent suppliers of rare earth magnets for EV traction motors in India include the following:

- Jatco (Thailand) Corporation Limited
- Tata AutoComp Systems Limited[168]
- Hyundai Mobis Corporation Limited.[169]

Significant manufacturers of rare earth magnets for brushless DC motors and permanent magnet synchronous motors (PMSM) include:

- Compage Automation Systems Private Limited
- Mark Elektriks.

Manufacturers of wind turbines that need NdFeB magnets and have a significant market share in India include the following:

- Siemens Gamesa[170]
- Vestas[171]
- General Electric[172]
- ReGen Powertech.

Notes:

165. https://dae.gov.in/writereaddata/parl/budget2015/rsus1229.pdf
166. https://ibm.gov.in/?c=pages&m=index&id=1473
167. https://www.irel.co.in/documents/20126/0/EoI+for+Nd+Magnet.pdf/49e306fb-7b54-cd70-fdb9-c56e4c0fe0f9?t=1600083348672
168. https://tataautocomp.com/
169. Information Platform (marklines.com)
170. https://onlinelibrary.wiley.com/doi/full/10.1002/we.2499
171. https://www.sciencedirect.com/science/article/pii/S0301420717300077
172. https://www.researchgate.net/publication/257935440_Direct-drive_permanent_magnet_generators_for_high-power_wind_turbines_Benefits_and_limiting_factors

Supply scenario in India

During 2020, global production of rare earth oxide equivalent was estimated at 240 kt. Global economic resources of rare earth oxides are expected to reach 115 Mt in 2021.[173]

According to China's Ministry of Industry and Information Technology, in 2020, the country had a mine production quota of 140 Mt of rare earth oxides, with 121 Mt allocated to light rare earth oxides.[174] It accounts for 63 percent of the global production. Its economic resources of rare earth oxides accounted for 37 percent of the global economic resources of rare earth oxides in 2019.[175]

In 2020, India produced 3 kt of rare earth oxides. This was equivalent to about 3 percent of the global economic resources of rare earth oxides (about 6.9 Mt), ranking India sixth globally.[176]

The principal sources of REEs globally are bastnasite, a fluorocarbonate that occurs in carbonatites and related igneous rocks; xenotime (yttrium phosphate), which is commonly found in mineral sands deposits; loparite, which occurs in alkaline igneous rocks; and monazite, a phosphate.[177]

As per the Indian Bureau of Mines (IBM), monazite is the key source of REEs. Indian monazite primarily consists of LREEs such as 46 percent cerium, 22 percent lanthanum, 20 percent neodymium, 5 percent praseodymium, and about 2.5 percent samarium. IREL is the primary producer of India's REEs.

India's midstream and downstream REE value chains are not well developed, making the country dependent on imports of RE magnets, including neodymium magnets, which are the most widely used. The key challenge in India is the technology for processing of REO into RE metals, alloys and production of magnets across midstream of value chain. The current value chain has a very few players making permanent magnets (only for small motor applications). Presently , India lacks the scale, experience and resources of the global companies, and may be assisted by public-funded R&D efforts, to develop efficient technologies and funding and participation from private sector in the development of mid-stream of the RE value chain.

The following table lists the duties the Indian Government imposes imported LREEs.

Table 27: Import duties on LREE products in April 2021[178]

	HS code	BCD	SWS	IGST	Total duties
Permanent magnets and articles intended to become permanent magnets after magnetisation of other material	85051190	7.5%	10%	18%	27.74%
Permanent magnets and articles intended to become permanent magnets after magnetisation of other material	85051900	7.5%	10%	18%	27.74%

Note: The IGST is applicable on both imports and Indian manufacture and is an eligible 'input tax credit', which can be offset against GST liability.

Notes:

173. https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-rare-earths.pdf
174. https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-rare-earths.pdf
175. Australian Critical Minerals Prospectus 2020
176. Australian Critical Minerals Prospectus 2020
177. https://ibm.gov.in/writereaddata/files/12272016154439IMYB2015_Rare%20Earth_27122016_Adv.pdf
178. CBIC - Ministry of Commerce, GOI

Australian supply capability

In 2019, Australia had economic resources of 4,030 kt of rare earth oxides, representing 4 percent of the global economic resources of rare earth oxides and ranking sixth in the world. Australia ranks fourth worldwide in terms of rare earth oxides production, manufacturing 18 kt of rare earth oxides in 2019; almost all of which is from the Mount Weld mine owned by Lynas Rare Earths.[179]

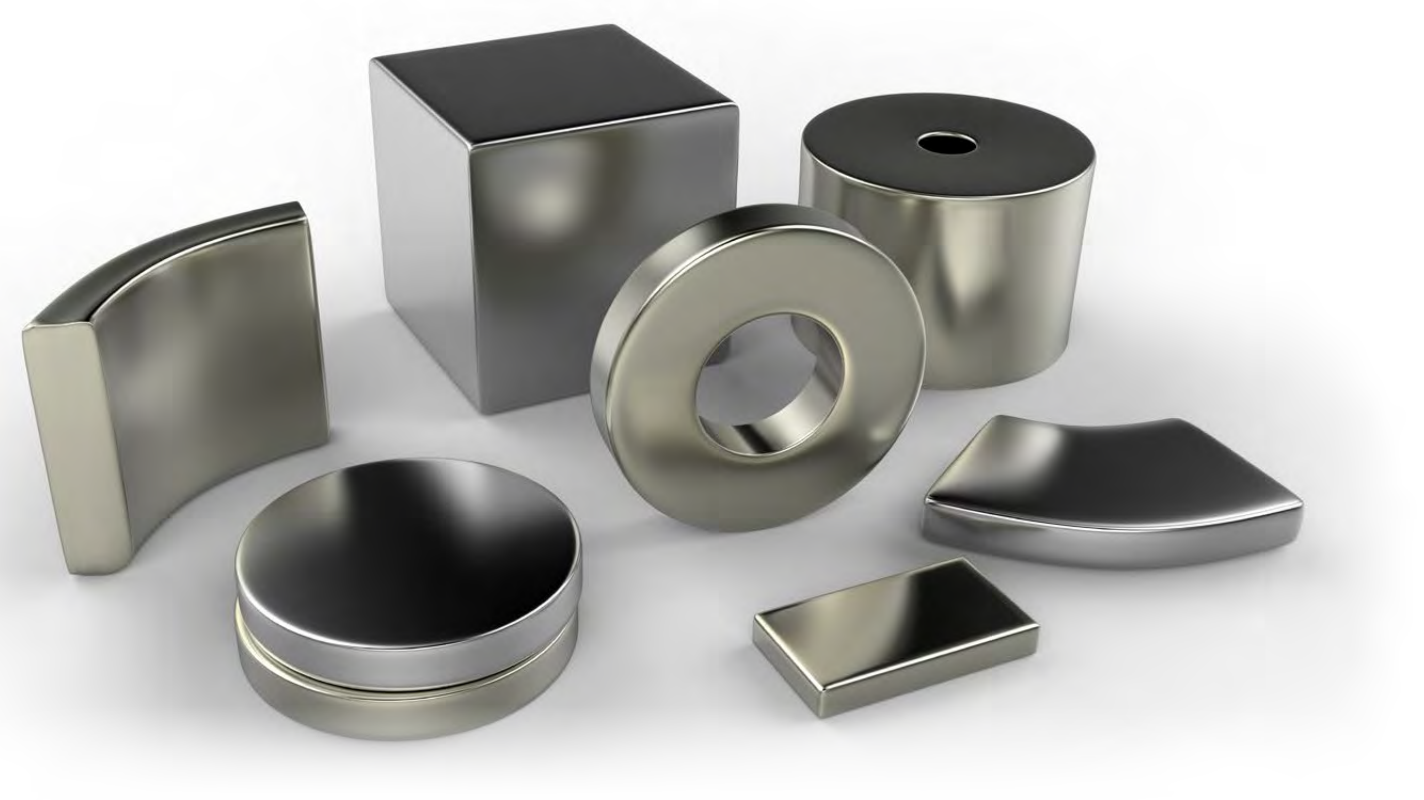
Mount Weld produced 19.7 kt of rare earth oxides, containing 5.9 kt of NdPr in 2019, via its processing plant in Malaysia.[180] Iluka now also produces zirconium rare earth oxide concentrate from a stockpile of historical monazite-rich material at its Eneabba mineral sands mine.

Australia has a number of key advanced REE projects that can be divided into two broad categories:

1. Hard rock projects of several different geological styles (the Mount Weld mine and the Nolans, Dubbo, Yangibana, and Browns Range projects)
2. Mineral sands projects with high REE content, typically associated with high zircon content (for example, the Eneabba stockpile operation, Donald Mineral Sands, WIM150, Fingerboards, and Avonbank projects).

Four of these Australian projects are in pre-construction stage and another four have completed bankable feasibility studies. Some of them are expected to come online in the near term.

Australia also has a number of additional earlier-stage REE projects.[181]



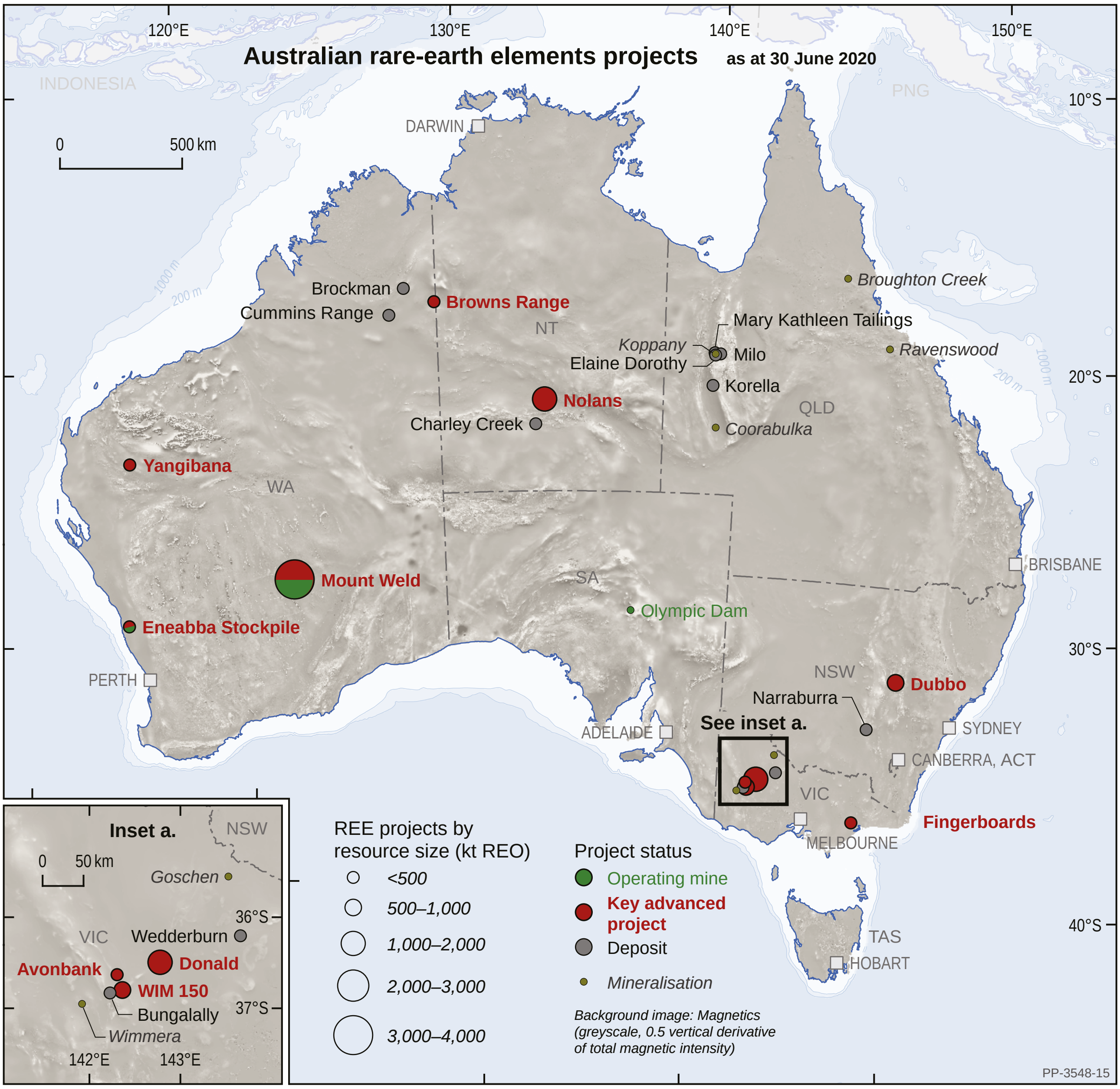
Notes:

179. Australia's Identified Mineral Resources, 2019 Geoscience Australia; www.ga.gov.au/digital publication/aimr2020/world-rankings

180. Australian Critical Minerals Prospectus 2020, Austrade

181. Geoscience Australia

Figure 32: Australian REE projects



Source: Australian Critical Minerals Prospectus 2020

Table 28: Australia's upcoming LREE projects

Critical mineral	Project name	Company	Project status	Primary mineral(s)	Tonnage (Mt)	Grade	Units		Contained (kt)
REE	**Mount Weld**	Lynas Corporation Ltd	Operating	REE	55.4	5.40	%	TREO	3,000
REE	**Olympic Dam**	BHP	Operating	REE					N/A
REE	**Eneabba Stockpile**	Iluka Resources Ltd	Operating	Zr, REE, Ti	1.0	10.34	%	TREO	103
REE	**Nolans**	Arafura Resources Ltd	Pre-const	REE, P	56.0	2.60	%	TREO	1,456
REE	**Dubbo**	Alkane Resources Ltd	Pre-const	Zr, Nb, Hf, Ta, REE	75.2	0.88	%	TREO	662
REE	**Yangibana**	Hastings Tech. Metals Ltd	Pre-const	REE	21.3	1.12	%	TREO	238
REE	**Browns Range**	Northern Minerals Ltd	Pre-const	REE	9.3	0.67	%	TREO	57
REE	**Donald**	Astron Ltd	FS	Zr, Ti, REE	2,427.0	0.06	%	TREO	1,398
REE	**WIM 150**	Murray Zircon Pty Ltd	FS	Zr, Ti, REE	1,650.0	0.06	%	TREO	908
REE	**Fingerboards**	Kalbar Resources Ltd	FS	Zr, Ti, REE	530.0	0.09	%	TREO	490
REE	**Avonbank**	WIM Resource Pty Ltd	PFS	Zr, Ti	490.0	0.06	%	TREO	308

REE heavy mineral sands project summaries (Donald, WIM 150, Fingerboards and Avonbank) are included in the titanium section.

Potential project cooperation opportunities

India's demand for minerals required for rare earth permanent magnets will depend on its progress in manufacturing these magnets, given the Indian Government's policies to encourage domestic capabilities.

Key opportunities

- Australian companies could engage with Indian private-sector companies, such as Tata Group, Aditya Birla, Mahindra Limited, Permanent Magnets Limited, Dura Magnets, and MAHLE for offtake arrangements from advanced Australian REE projects.
- Australian METS providers could explore supply of processing technologies for Indian refining and separation facilities in the intermediate value chain.
- Australian project owners could explore strategic partnerships with Indian public sector companies, such as IREL and NMDC, to invest in midstream processing of REE concentrates into rare earth oxides or mixed rare earth carbonates. Projects could be located in Australia or India provided the challenges of transporting and processing radioactive REE concentrates in India could be addressed.
- Companies could explore a tripartite collaboration with countries that can help bridge the gap in intermediate processing capabilities, such as Japan, South Korea, Germany, and the US.
- Australian and Indian institutions could collaborate to research REE deposit geology in India, incorporating the latest global knowledge of REE deposit styles, to facilitate the development of Indian REE projects.

Heavy rare earths

HREEs are defined by their higher atomic weights relative to LREEs. As they are less common than LREEs, demand is outpacing supply. Moreover, some elements are in short supply. This typically makes HREEs more valuable than LREEs, although the market for HREEs is smaller.

Dysprosium and terbium are considered critical elements in the HREE metals group, as supply levels are low. They are increasingly important in the development of clean energy technologies.

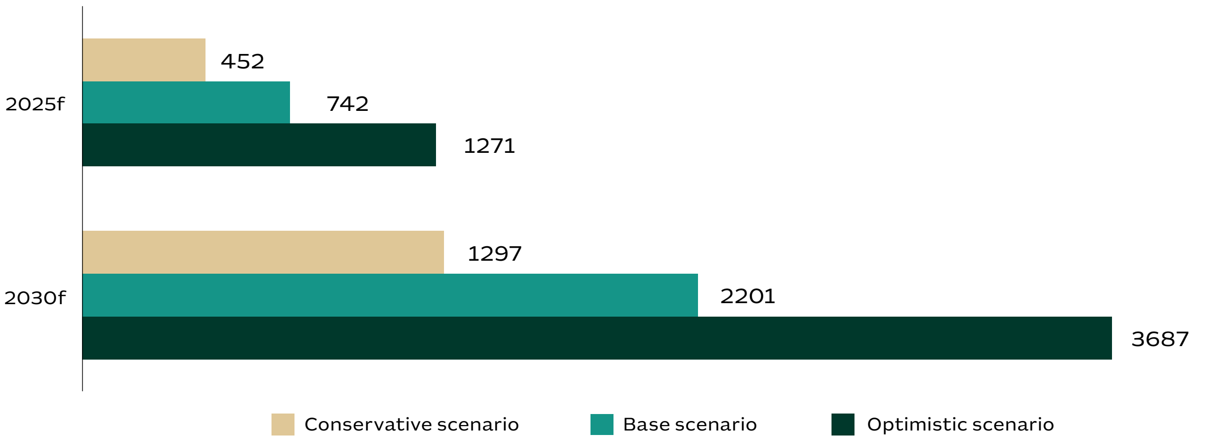
Similar to LREEs, HREEs play a critical role in other emerging technologies, including EVs, fibre optics, and medical devices. Dysprosium is primarily used to manufacture NdFeB magnets.

Indian market analysis

1. Dysprosium

The Indian dysprosium market was nearly 68 tonnes in 2020. It is projected to reach a cumulative demand potential of 1,297–3,687 by 2030. [182]

Figure 33: Cumulative Indian dysprosium market demand potential (tonnes)[183]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	1271	742	452	3687	2201	1297

Disclaimer: The demand potential identified shall be subject to the expected development of manufacturing competence in India

Dysprosium elements are used to manufacture bonded and sintered NdFeB magnets for EV traction motors and wind turbine generators to improve magnet performance.

Dysprosium quantity varies for different types of EVs. E-bike magnets require about 1 percent of dysprosium, while other EV magnets require about 7.5 percent.[184] Wind turbine magnets require nearly 7 percent of dysprosium.[185] The percentage of dysprosium in NdFeB magnets is usually 0.8-1.2 percent.

Notes:

182. Based on demand for NdFeB magnets in India and the need for dysprosium in manufacturing NdFeB magnets

183. Analysis based on information available in following reports: NITI Aayog, India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey, The unexpected trip: The future of mobility in India beyond COVID-19; CRISIL, By 2024, nearly half of new 3-wheelers sold will be e-autos; Avendus, Electric Vehicles: Charging towards a bright future, July 2020; ICRA press release 2020; Global Wind Energy Council, India Wind Outlook towards 2022. UN Comtrade Permanent Magnets Import Export Data. 2020 represents actual consumption for the year based on imports; 2025f and 2030f represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.

184. Edison, EVs and rare earths: Key to the electric revolution

185. https://www.sciencedirect.com/science/article/pii/S2214993716300641

2. Terbium

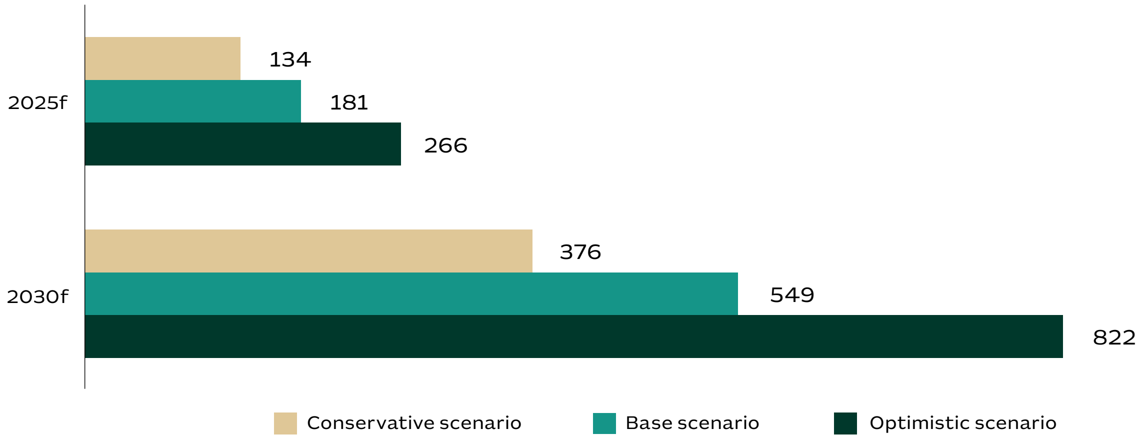
Terbium is used to manufacture LCD and plasma screens, missile guidance systems, permanent magnets, solid-state electronics, and sonar systems. Overall, 22 percent of the terbium production is used to manufacture permanent magnets, while 48 percent is used to produce phosphors.

Terbium could be used as an alternative to dysprosium in magnet production. However, the annual supply of terbium is far more limited than that of dysprosium, typically at a supply ratio of 1:4.[186]

China is the largest global producer of terbium. In 2019, the country exported about 115 tonnes of terbium, of which, nearly 94 percent was exported to Japan (87.3 percent) and the US (6.4 percent). China exported 7.2 tonnes of terbium to other countries, including India.[187]

India's cumulative demand potential for terbium for NdFeB magnets is expected to be 549 tonnes by 2030. The country currently has small terbium traces in its monazite supply (consisting of 0.06 percent terbium).

Figure 34: Cumulative demand potential for terbium in India based on requirement in NdFeB magnets (tonnes)[188]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	266	181	134	822	549	376

Disclaimer: The demand potential identified shall be subject to the expected development of manufacturing competence in India

Notes:

186. Roskill, Rare Earths: Changing magnet compositions to manage supply availability
187. https://www.visualcapitalist.com/chinas-dominance-in-rare-earth-metals/
188. Analysis based on information available in following reports: NITI Aayog, India's Electric Mobility Transformation Progress To Date and Future Opportunities; McKinsey, The unexpected trip: The future of mobility in India beyond COVID-19; CRISIL, By 2024, nearly half of new 3-wheelers sold will be e-autos; Avendus, Electric Vehicles: Charging towards a bright future, July 2020; ICRA press release 2020; Global Wind Energy Council, India Wind Outlook towards 2022; UN Comtrade Permanent Magnets Import Export Data. 2020 represents actual consumption for the year based on imports; 2025f and 2030f represent cumulative numbers, based on population of vehicles and installed capacities of ESS in those years.

3. Europium

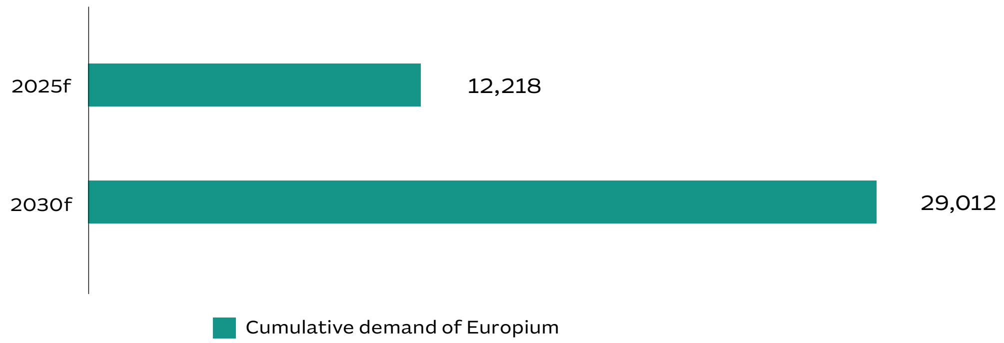
Europium oxide has a vital role in computer and television screens, as a phosphor that emits a pure red light. This red spectrum is why europium is used in low-energy light bulbs and powerful street-lighting mercury vapour tubes to create a more natural or warm light.

Europium is also employed in the medical field. The highly sensitive luminescence provided by europium, attached as a tag to complex biochemicals, assists in live tracing of these materials during living tissue research.

Due to its luminescent properties, europium oxide is the commonly traded form.

Demand for Light Emitting Diode (LED) bulbs that use europium was 70 million units in 2020, which equates to 1,600 kg of europium. At present, LEDs are mostly imported into India. India's demand for europium for manufacturing LED bulbs will increase to 4,000 kg by 2030. The cumulative demand for europium is forecast to reach 29 tonnes by 2030. [189]

Figure 35: Cumulative demand potential for europium used in manufacturing LED bulbs (kg) [190]



	2025f	2030f
Totla cumulative demand	12,218	29,012

Disclaimer: The demand potential identified shall be subject to the expected development of manufacturing competence in India

Key industry participants

NdFeB magnet manufacturing requires HREEs, including terbium and dysprosium. NdFeB magnet customers include:

- Permanent Magnets Limited
- Dura Magnets Private Limited
- MAHLE

Terbium and europium are needed to manufacture phosphors used in LEDs – terbium in green phosphors and europium in red phosphors.[191] Significant Indian LED manufacturers include the following:

- MIC Electronics Limited
- Avni Energy Solutions Private Limited
- Instapower Limited.

Notes:
189. Based on discussions with industry sources
190. Based on discussions with industry sources
191. https://pubs.usgs.gov/sir/2012/5215/pdf/sir2012-5215.pdf

Supply scenario in India

IREL Limited commissioned a new dysprosium plant in December 2020. The company has developed a process flowsheet to extract dysprosium from monazite at its rare earths division plant in Aluva, Kerala.

India mostly sources its dysprosium and terbium from China and Myanmar.[192] Australian suppliers have an opportunity to create a niche market to supply these minerals to India.

Import duties on NdFeB magnets requiring dysprosium or terbium are high, including BCD of 7.5 percent, IGST of 18 percent, and SWS of 10 percent. Total duties on importing permanent magnets to India are 27.74 percent.[193]

Table 29: Import duties on various HREE products from April 2021[194]

	HS code	BCD	SWS	IGST	Total duties
Permanent magnets and articles intended to become permanent magnets after magnetisation of other material	85051190	7.5%	10%	18%	27.74%
Permanent magnets and articles intended to become permanent magnets after magnetisation of other material	85051900	7.5%	10%	18%	27.74%
Lamps and LEDs	85395000	10%	10%	28%	40.8%

Note: The IGST is applicable on both imports and Indian manufacture and is an eligible 'input tax credit', which can be offset against GST liability.

Potential project cooperation opportunities

The market for rare earth metals is driven by their usage in magnets meant for hybrid and electric cars, as well as the increasing global shift towards clean energy. Other applications in defence and high-end electronics add to the projected demand for these minerals.

Key opportunities

- Indian resources have limited content of heavy rare earths (HREEs). Australian project owners could explore strategic partnerships with Indian public-sector companies to invest in processing or refining of Australian REE concentrates either in Australia or India.
- Australian companies could engage with Indian private-sector companies, either involved in magnet or LED manufacturing, for offtake arrangements from advanced Australian REE projects, to cater to the growing demand.
- Australian project owners could engage with Indian private sector companies for investments in Australian HREE projects, to ensure a long-term sustainable supply.
- Australian and Indian companies could explore a tripartite collaboration with other companies that can assist bridge the gap in the intermediate processing capabilities.

Notes:

192. JRC Science for Policy Report, The role of Rare Earth Elements in Wind Energy and E-Mobility, European Union 2020
193. https://www.cybex.in/indian-custom-duty/electro-magnets-permanent-articles-intended-hs-code-8505.aspx
194. CBIC, Ministry of Commerce, GOI

Vanadium

Due to vanadium's unique characteristics of high ductility, malleability, and corrosion resistance, it is in strong demand across the steel, alloy, and chemical industries.

The steel industry accounts for about 90 percent of the current demand for vanadium. The increasing momentum in the Vanadium Redox Flow Batteries (VRFB) technology may further bolster demand for vanadium in the longer term.

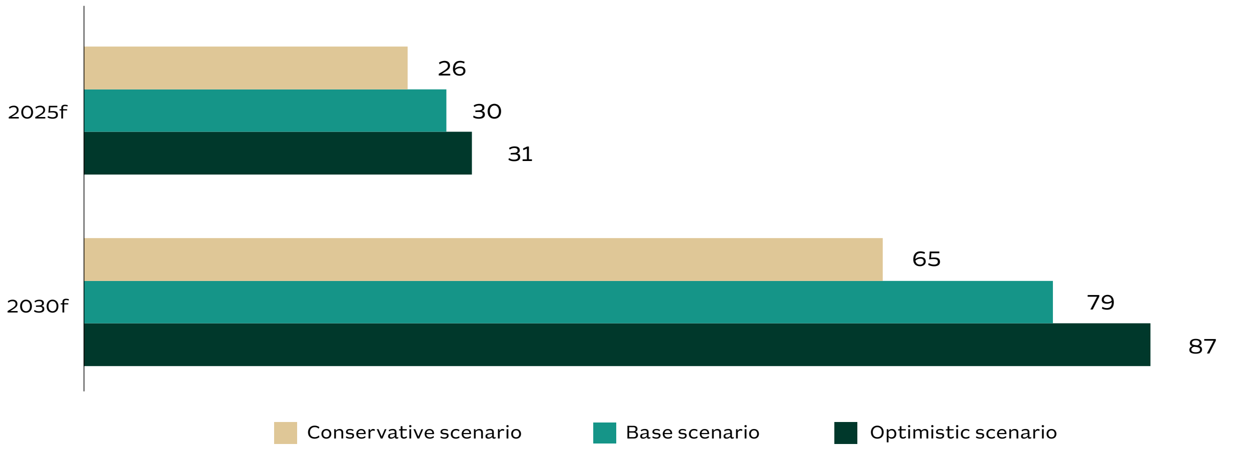
India's increasing demand for steel, expected future demand for vanadium in VRFB, limited domestic sources of vanadium, and heavy import dependence make vanadium a key critical mineral for India.

Australia has EDR of 6,019 kt in vanadium, the second highest globally.[195] There are significant opportunities to secure supplies of vanadium (commonly found in titanium deposits) from strategic offtake and investment partnerships in advanced vanadium mining projects in Australia.

Indian market analysis

India's vanadium market was estimated at 2.7 – 3.0 kt in 2020. The demand potential is expected to reach 65–87 kt by 2030.[196]

Figure 36: Cumulative Indian vanadium market demand potential (kt)[197]



	2025f			2030f		
Scenarios	Optimistic	Base	Conservative	Optimistic	Base	Conservative
Total cumulative demand	31	30	26	87	79	65

Disclaimer: The demand potential identified shall be subject to the expected development of manufacturing competence in India.

Notes:

195. Geoscience Australia - https://www.ga.gov.au/digital-publication/aimr2020

196. Analysis based on the following reports - vanadium requirement in steel production has been referred from Bushveld Minerals Vanadium 101 document of 03 May 2018; India is expected to replicate the global application trends and the same has been referred to from the blog Time to grab ferro vanadium-mjunction and Bushveld Minerals Vanadium 101 document of 03 May 2018

197. Analysis based on the following reports - vanadium requirement in steel production has been referred from Bushveld Minerals Vanadium 101 document of 03 May 2018; India is expected to replicate the global application trends and the same has been referred to from the blog Time to grab ferro vanadium-mjunction and Bushveld Minerals Vanadium 101 document of 03 May 2018

In India, vanadium is primarily used as an alloying element in iron and steel manufacturing. Special steels containing vanadium are used in manufacturing structural materials, automobile parts, tools, rails, surgical instruments, tubes, and pipes for corrosive materials, wind turbines, space vehicles, nuclear reactors, and defence equipment.

Vanadium is also used in master alloys, catalysts for chemicals, dyes for fabrics, pigments for ceramics, special-coated glasses, health preparations, electronics, miniature batteries, and superconducting magnets. These together account for 10 percent of the total vanadium demand.

VRFB's potential future demand may further increase vanadium demand as India develops its battery manufacturing capability. VRFB has the advantage of being scalable. Although the technology is currently nascent, it is expected to continue to develop over the next few decades.

While demand across various end-use industries is expected to increase, a flourishing Indian steel industry against a backdrop of ambitious economic development goals would drive demand for vanadium in the future.

Table 30: Indian vanadium market forecast by end-use segment[198]

End-use segment	2020e	2025f	2030f
Ferrovanadium	90%	88%	85%
Others (VRFB, master alloys, dyes, pigments, and others)	10%	12%	15%

In 2018, China introduced the high-strength rebar standard to limit and eliminate the use of inferior steel in construction. If India emulates this high-strength rebar standard, it could expect a substantial increase in demand for vanadium due to its high-strength properties.

If lithium vanadium oxide proves to be commercially viable as a high–energy density anode for lithium-ion batteries, ongoing developments in this application could significantly affect vanadium demand.

Vanadium oxide–based thin films also have characteristics suitable for applications, including optical switching, variable-emittance and anti-reflective surfaces, catalytic applications, infrared detectors, and thermochromic devices for smart thermal control systems in the aerospace sector.

Key industry participants

In India, the ferroalloy industry is most significant vanadium consumer, where demand for vanadium from ferrovanadium producing units is primarily met by importing vanadium pentoxide (V_2O_5) concentrates.

In India, vanadium sludge is produced as a by-product during the production of alumina hydrate, including the following operations:

- Bharat Aluminium Company Limited and Vedanta Resources' Lanjigarh plant
- Hindalco Industries Limited's Belgavi plant

Notes:

198. Analysis based on the following reports - vanadium requirement in steel production has been referred from Bushveld Minerals Vanadium 101 document of 03 May 2018; India is expected to replicate the global application trends and the same has been referred to from the blog time to grab ferro vanadium-mjunction and Bushveld Minerals Vanadium 101 document of 03 May 2018

National Aluminium Company Limited (NALCO) and Reliance Industries Limited (RIL) have completed lab-scale studies to successfully recover vanadium but they are not yet producing vanadium sludge on a commercial scale[199].

As vanadium recovery highly depends on improvements in alumina production, India will find it challenging to generate an adequate quantity of vanadium sludge to meet increasing domestic demand in the near term.

Significant developments in vanadium redox flow batteries may also increase interest in vanadium amongst battery manufacturers.

Table 31: Potential end-use industries and players[200]

User segment	Technology/ products	End-use industries	Mineral/alloy specification	Key industry players	Key geographical locations
Ferroalloys	Ferrovanadium	Steel	V_2O_5	Essel Mining and Industries Limited, Rama Ferro Alloys & Finance Private Limited, Shiva Industries Private Limited, Refracast Metallurgical Private Limited, and Premier Alloys & Chemicals Private Limited	Manufacturers are spread across the country
Others	Dyes, pigments, catalysts	Ceramics, fabrics, glass, electronics etc.	V_2O_5 and vanadium concentrate	Jammu Pigments Limited, Mittal Pigments Private Limited, and Gurushree Industries Private Limited	Manufacturers are spread across the country

Supply scenario in India

Vanadium is typically found within magnetite iron ore deposits; it is largely mined as a co-product, not a primary mineral. About 80–85 percent of the world's vanadium is sourced from three countries – China, Russia, and South Africa. China supplies nearly 60 percent of the global market.[201]

India imports vanadium in various forms, including ores, concentrates, and flakes. In 2019, it imported about 13 kt, increasing to nearly 3.3 kt in 2020.[202]

Although India is a major vanadium consumer, it is not a primary producer. IBM's 2019 National Mineral Inventory estimated India's vanadium resources at 24.6 Mt, with an estimated V_2O_5 content of 64.6 kt, mainly in Karnataka, Odisha, and Maharashtra.[203] Although these have the potential to be mined in the future, this would require significant R&D investments.

The Geological Survey of India has explored a promising concentration of vanadium in Arunachal Pradesh, but the deposit has not been fully studied.[204]

Notes:

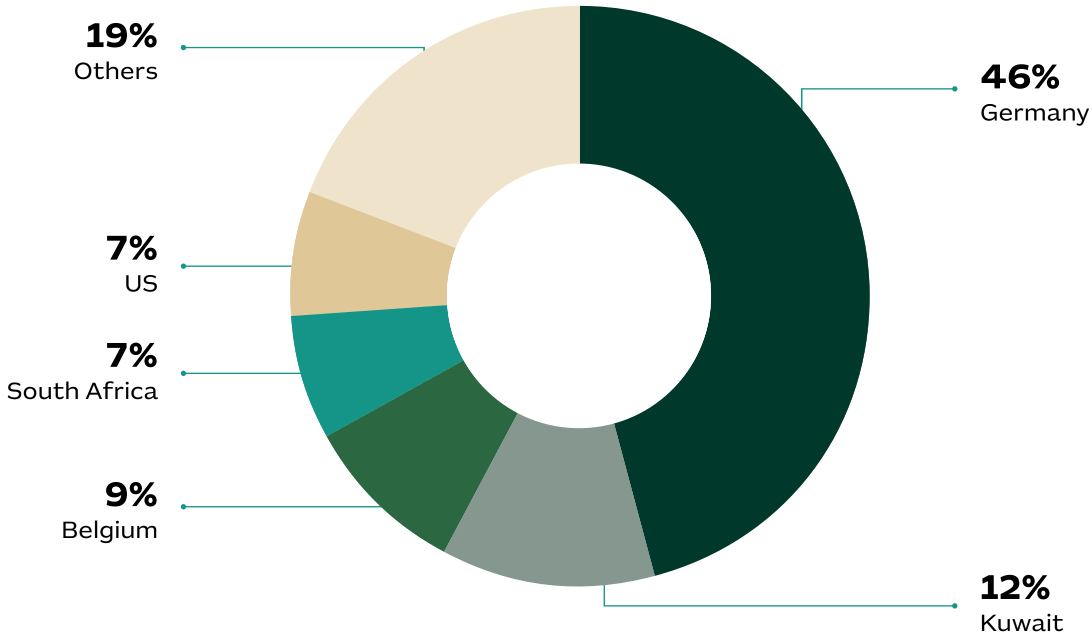
199. Indian Minerals Yearbook ,2019, https://ibm.gov.in/writereaddata/files/06052020113429Vanadium_2019.pdf
200. Based on primary and secondary research
201. Bushveld minerals- https://www.bushveldminerals.com/about-vanadium/
202. UNCOMTRADE, ITC Trade map and India Trade Statistics
203. Indian Minerals Yearbook ,2019, https://ibm.gov.in/writereaddata/files/06052020113429Vanadium_2019.pdf
204. Geological Survey of India

In 2018–19, India's reported production of vanadium as a by-product from slag in alumina refineries was about 442 tonnes.[205]

Table 32: Indian imports of vanadium concentrates and compound[206]

Import product description	HS code	2019		2020	
		Volume (kt)	Value (A$ million)	Volume (kt)	Value (A$ million)
Vanadium ores and concentrates	26159010	6.98	7.35	1.12	1.22
V_2O_5 flakes	28253010 and 28253090	6.00	43.60	2.17	10.51
Ferrovanadium	72029200	0.44	14.84	0.43	7.79*

Figure 37: Imports of vanadium ores and concentrates in 2020[207]



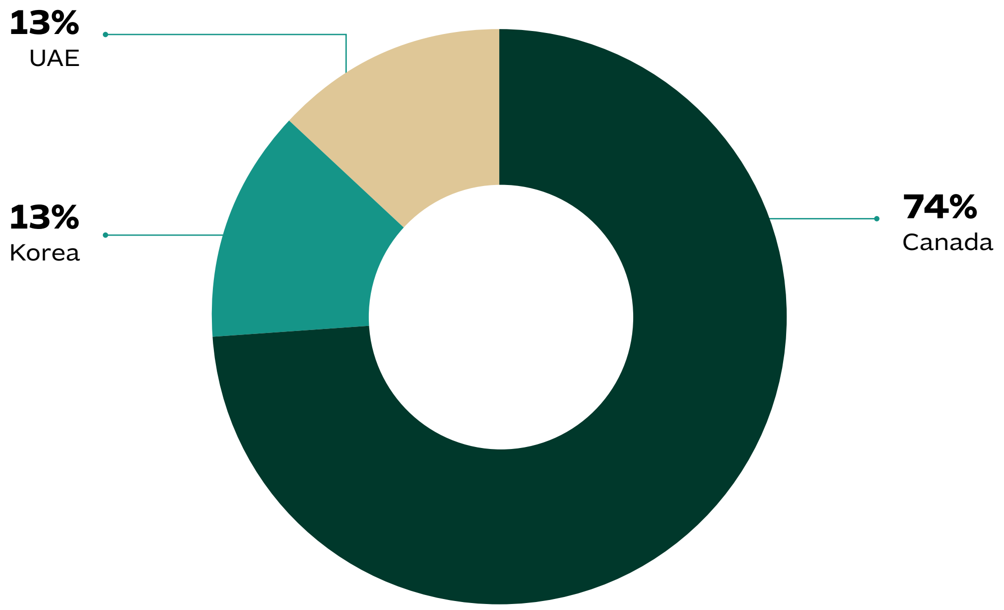
Notes:

205. Indian Minerals Yearbook ,2019, https://ibm.gov.in/writereaddata/files/06052020113429Vanadium_2019.pdf

206. UNCOMTRADE and India Trade Statistics; *The high variation in value of imports over the years is on account of the high volatility of ferrovanadium prices, from about A$107/kg in March 2019 to about A$40/kg in May 2020 – https://www.vanadiumprice.com/

207. UNCOMTRADE and India Trade Statistics

Figure 38: Imports of vanadium pentoxide flakes in 2020[208]



The following table lists the duties imposed by the Indian Government on the import of vanadium in various forms.

Table 33: Import duties on various vanadium products from April 2021[209]

Category	HS code	BCD	SWS	IGST	Total duties
Vanadium ores and concentrates	26159010	5%	10%	5%	10.25%
V_2O_5 flakes	28253010 and 28253090	10%	10%	5%	15.5%
Ferrovanadium	72029200	15%	10%	18%	35.7%

Note: The IGST is applicable on both imports and Indian manufacture and is an eligible 'input tax credit', which can be offset against GST liability.

In addition to import duties on vanadium ores, concentrates, and compounds, the Indian Government has imposed a basic customs duty of 15 percent on ferrovanadium to support India's domestic manufacturing industry.

International prices for V_2O_5 were around A$ 14,700–22,400 per tonne in 2019.[210] Vanadium demand can be closely linked to crude steel production. Therefore, a robust outlook for the steel industry means vanadium prices should trend upwards by 2030.

With no known vanadium mining activity and limited domestic availability, India will continue to rely on imports. This presents an opportunity for Australia's vanadium miners to supply various Indian V_2O_5 buyers across industries at competitive prices.

Notes:

208. UNCOMTRADE and India Trade Statistics
209. CBIC – Ministry of Commerce, GOI
210. Viewpoint: V demand to be driven by alternative sources, Argus media

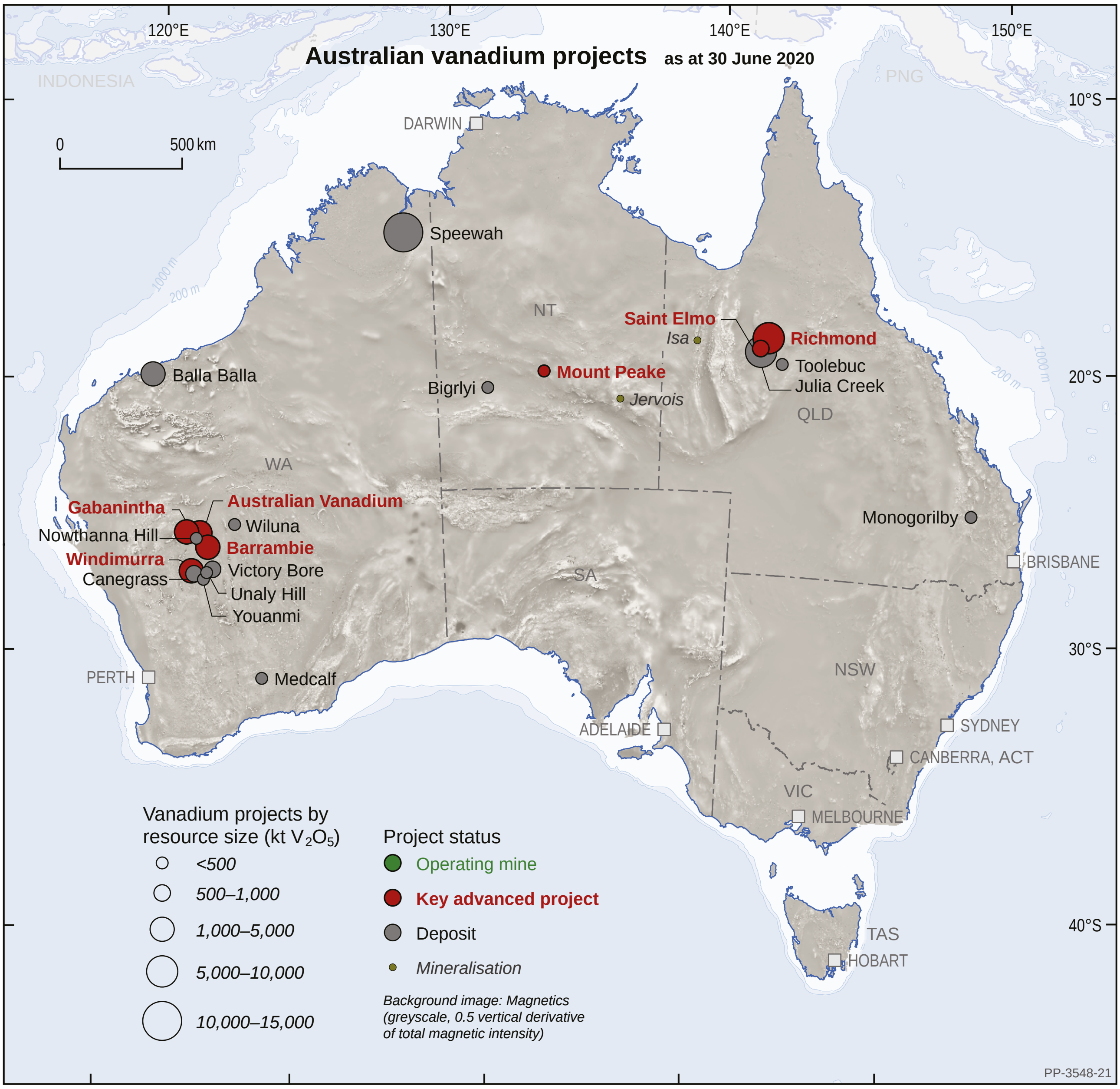
Australian supply capability

Australia has economic resources of 6,019 kt of contained vanadium, representing 20 percent of the global economic resources and placing Australia third in global rankings.[211]

Although Australia has no operating vanadium mines, there are a number of advanced vanadium projects; of which, most are associated with titanium. Increasing vanadium demand, spurred by rising steel and battery demand, has also encouraged new exploration and feasibility studies for mothballed projects.

Most of Australia's vanadium projects are igneous hard rock deposits, with vanadium and titanium associated with magnetite. The majority plan to produce vanadium and titanium for sale but not magnetite.

Figure 39: Australian vanadium projects



Source: Australian Critical Minerals Prospectus 2020

Notes:

211. Geoscience Australia- https://www.ga.gov.au/digital-publication/aimr2020

Table 34: Australia's key advanced vanadium V_2O_5 projects

Critical mineral	Project name	Company	Project status	Primary mineral(s)	Tonnage (Mt)	Grade	Units		Contained (kt)
Vanadium	**Windimurra**	Atlantic Ltd	Pre-const	V	234.0	0.49	%	V_2O_5	1,146
Vanadium	**Balla Balla**	BBI Group Pty Ltd	FS	V, Ti	455.9	0.66	%	V_2O_5	2,988
Vanadium	**Barrambie**	Neometals Ltd	FS	Ti, V	280.1	0.44	%	V_2O_5	1,234
Vanadium	**Gabanintha**	Technology Metals Au Ltd	FS	V, Ti	131.0	0.80	%	V_2O_5	1,179
Vanadium	**Mount Peake**	TNG Ltd	FS	V, Ti, Fe	160.0	0.28	%	V_2O_5	448
Vanadium	**Richmond – Julia Creek**	Horizon Minerals; RVT	PFS	V, Mo, Ni	1,838.0	0.36	%	V_2O_5	6,650
Vanadium	**Australian Vanadium Project**	Australian Vanadium Ltd	PFS	V, Ti	208.2	0.74	%	V_2O_5	1,541
Vanadium	**Saint Elmo**	Multicom Resources	PFS	V, Mo	304.5	0.25	%	V_2O_5	762
Vanadium	**Medcalf**	Audalia Resources Ltd	PFS	V, Ti	32.0	0.47	%	V_2O_5	149
Vanadium	**Wiluna**	Toro Energy Ltd	PFS	U, V	96.3	0.03	%	V_2O_5	31
Vanadium	**Bigrlyi**	Energy Metals Ltd	PFS	U, V	7.5	0.12	%	V_2O_5	9

Source: Australian Critical Minerals Prospectus 2020

Potential project cooperation opportunities

Vanadium is used primarily as an alloying element in a growing iron and steel industry, and stabiliser in titanium and aluminium alloys for aerospace applications.

Key opportunities

- Australian vanadium project proponents could explore offtake opportunities in traditional sectors, such as steel, chemicals, and other alloys, with Indian companies (including MIDHANI, Essel Mining & Industries Limited, Rama Ferro Alloys & Finance Private Limited, Shiva Industries Private Limited, and Premier Alloys & Chemicals Private Limited).

- Companies in the Indian steel, chemicals, and alloy industries could consider strategic investment in advanced Australian vanadium projects to secure supply. Many Australian vanadium projects (igneous hard rock deposits) also have associated titanium, enabling potential supply of vanadium and titanium from the same project.

- Acknowledging the potential for VRFB development in India, Australian vanadium projects could initiate dialogue with Indian battery manufacturers for the joint development of technology for downstream vanadium electrolyte processing. Potential partners include Tata Chemicals, Nexcharge (Exide–Leclanché), and TDSG.

- Australian institutions could explore collaborative research models with Indian organisations, such as ARCI, MIDHANI, IESA, and other institutes, to support commercialisation of processing and recycling technologies.

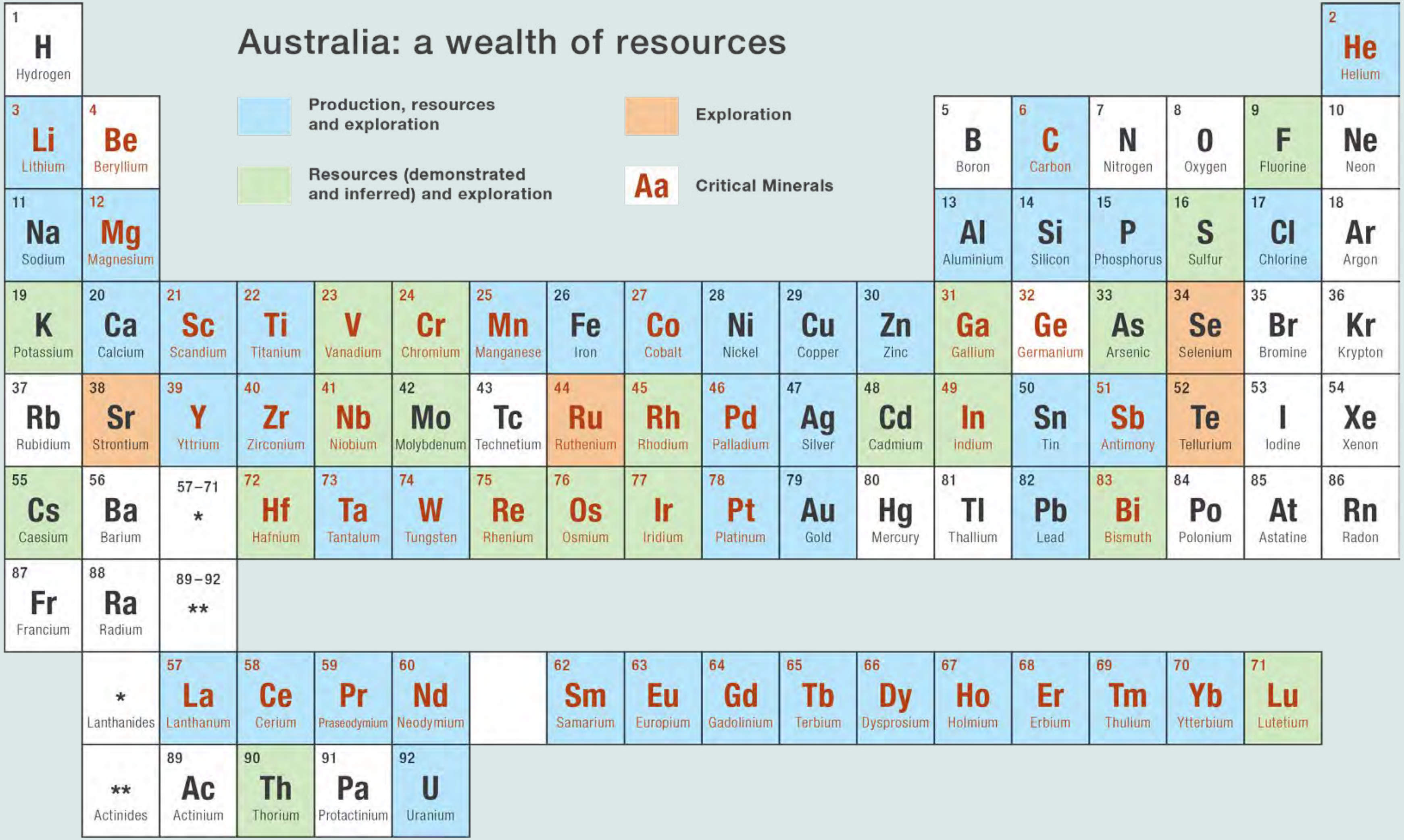
ANNEX

Table 35: List of lithium-ion battery ecosystem players in India[212]

Company	Partnerships	Location of plant	Year announced	Details
TDSG	**Suzuki, Toshiba and DENSO (50%, 40% and 10%, respectively)** **JV – American Electric Power Company**	Gujarat	January 2020	• Cell technology – Toshiba; module technology – DENSO • Target sector – EVs • Phase 1 was initiated in 2018 and is expected to be completed by December 2020. The investment was INR1,150 Cr (A$225 million) • Planned investment for phase 2 production of lithium-ion batteries is INR3,715 Cr (A$726 million)
ACME Cleantech		Uttarakhand		• The current operating capacity is 350 MWh, mainly providing a stationary storage solution • Planned to ramp up to 2–3 GWh
Pinnacle India	**Phylion, China**	Pune	January 2020	• Battery cell technology – Phylion • Target sector – light passenger and commercial EVs • Yet to be operational
Exide	**Exide (75%) and Leclanché SA (25%)** **JV – Nexcharge**	Gujarat	June 2018	• Battery cell technology – Leclanché SA • Capacity – 1.5 GWh • Target sector – EVs, grid storage and other stationary storage • Yet to be operational
XNRGI India	**Own technology**	Gurugram	2019	• Opened a 240 MWh battery plant in Gurugram in 2020, targeted at EVs • Plans to expand to GWh scale as demand picks up
BHEL ISRO	**MOU between ISRO and BHEL**	Bangalore	2018	• ISRO transferred its ion cell technology to BHEL • BHEL plans to set up GWh-scale manufacturing setup
Tata Chemicals	**MOU with ISRO**	Gujarat	2019	• Plans to set up a 10 GWh lithium-ion battery plant • Target sectors – EVs and stationary storage
Renon India	**Ahamani EV tech**	Surat, Gujarat	2019	• 200 MWh capacity, with target to expand to 1 GWh in the next few years • Target sectors – EVs, solar appliances, lights etc. • Yet to be operational
Li Energy	**CSIR technology**	Tamil Nadu	2020	• Plans 1 GWh integrated manufacturing plant, to be set up in phases • Talks underway with Contemporary Amperex Technology Co. Limited to supply cells in the initial year
Greenko		To be decided	2020	• Announced US$1 billion investment plan for battery manufacturing
Exicom Okaya				• Assembles and supplies battery packs to 2-wheel, 3-wheel, e-rickshaws etc.

Notes:

212. News articles, company annual reports, industry reports


Australia: a wealth of resources
Production, resources and exploration
Resources (demonstrated and inferred) and exploration
Exploration
Aa Critical Minerals
1 H Hydrogen
2 He Helium
3 Li Lithium
4 Be Beryllium
5 B Boron
6 C Carbon
7 N Nitrogen
8 O Oxygen
9 F Fluorine
10 Ne Neon
11 Na Sodium
12 Mg Magnesium
13 Al Aluminium
14 Si Silicon
15 P Phosphorus
16 S Sulfur
17 Cl Chlorine
18 Ar Argon
19 K Potassium
20 Ca Calcium
21 Sc Scandium
22 Ti Titanium
23 V Vanadium
24 Cr Chromium
25 Mn Manganese
26 Fe Iron
27 Co Cobalt
28 Ni Nickel
29 Cu Copper
30 Zn Zinc
31 Ga Gallium
32 Ge Germanium
33 As Arsenic
34 Se Selenium
35 Br Bromine
36 Kr Krypton
37 Rb Rubidium
38 Sr Strontium
39 Y Yttrium
40 Zr Zirconium
41 Nb Niobium
42 Mo Molybdenum
43 Tc Technetium
44 Ru Ruthenium
45 Rh Rhodium
46 Pd Palladium
47 Ag Silver
48 Cd Cadmium
49 In Indium
50 Sn Tin
51 Sb Antimony
52 Te Tellurium
53 I Iodine
54 Xe Xenon
55 Cs Caesium
56 Ba Barium
57–71 *
72 Hf Hafnium
73 Ta Tantalum
74 W Tungsten
75 Re Rhenium
76 Os Osmium
77 Ir Iridium
78 Pt Platinum
79 Au Gold
80 Hg Mercury
81 Tl Thallium
82 Pb Lead
83 Bi Bismuth
84 Po Polonium
85 At Astatine
86 Rn Radon
87 Fr Francium
88 Ra Radium
89–92 **
* Lanthanides
57 La Lanthanum
58 Ce Cerium
59 Pr Praseodymium
60 Nd Neodymium
62 Sm Samarium
63 Eu Europium
64 Gd Gadolinium
65 Tb Terbium
66 Dy Dysprosium
67 Ho Holmium
68 Er Erbium
69 Tm Thulium
70 Yb Ytterbium
71 Lu Lutetium
** Actinides
89 Ac Actinium
90 Th Thorium
91 Pa Protactinium
92 U Uranium

AUSTRALIA