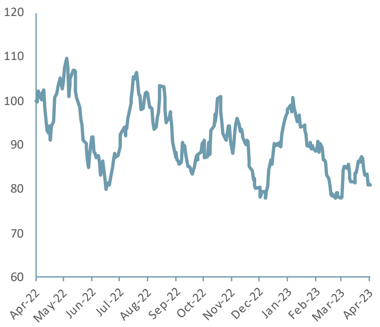
THEMATIC

EV Market 23E
$2,404bn



MVIS Global Rare Earth/Strategic Metals Index

Wednesday, 26 April 2023

Key Metrics	
Price	**RMB/mt**
Lanthanum oxide	6,650
Cerium oxide	6,800
Praseodymium oxide	545,000
Neodymium oxide	570,000
Samarium oxide	15,000
Europium oxide	195
Gadolinium oxide	272,500
Terbium oxide	9,650
Dysprosium oxide	2,010
Erbium oxide	257,500
Yttrium oxide	49,500
NdPr oxide	535,000

Business Activity
Rare Earth Metals

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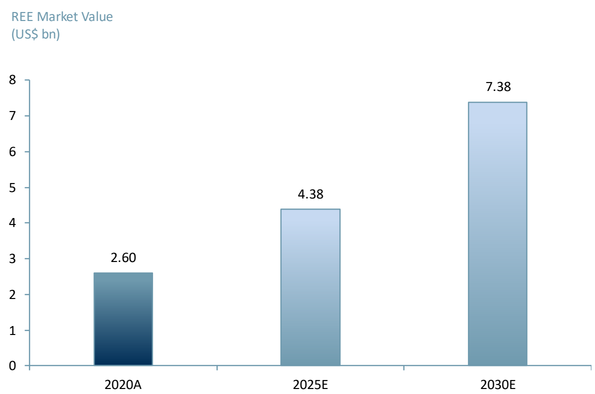
Rare Earth Elements Market

Permanent Magnets to Lead REE Market

Rare Earth Elements (REEs) are key to the new clean energy economy. REEs are a set of 17 elements with unique physical and chemical properties used across a range of industrial and technological applications. The largest use of REEs is the production of permanent magnets – a critical component of clean energy applications (e.g., electric vehicles and wind turbines). We expect strong demand gr% in 22-32E for magnet rare earths, including neodymium, praseodymium and dysprosium. China dominates REE mining supply, producing ~57% of the world's REE output. Chinese REE market dominance is a global strategic concern because REEs are essential materials for electric cars, defence applications and net zero electricity generation via e.g., wind turbines and solar panels. Countries, such as the US and Australia and sectors such as Autos are investing significantly in their own capacity/supply chains.

- The global rare earths market was valued at ~ US$ 2.6bn 2020A;
- We forecast the REE market to touch US$ 7.4bn in 2030E;
- Permanent magnets equal ~90% of REE market by value;
- China produces ~90% of permanent magnets globally.



Investment Case (Generalised)

Rare Earth Elements are increasingly sought-after resources because of their critical use in high-technology and low carbon applications.

UN Climate Change Conference (COP26) Nov21 supports demand for REEs.

The climate commitment made at United Nations Climate Change Conference (COP26) held in Glasgow in November 2021 by governments across the world, will accelerate and help increase demand for these elements. The rare earth elements are currently key to enabling the global green energy transition.

The pathway to decarbonisation includes electrification of the economy, more solar and wind generation and production of electric vehicles (EVs). These technologies all consume REEs.

EV global sales hit 5.6m in 2021A.

EVs make up 7% of the global auto market.

Global sales of electric vehicles reached 5.6m in 2021A, according to Bloomberg NEF, with EVs now making up 7% of the global auto market. Bloomberg NEF projects that annual sales of EVs will double again in 2022 to 10.5m.

The production of EVs and low carbon technologies will ultimately rely on a steady supply of REE and rare earth oxides (REOs) / minerals.

Green technologies require raw materials such as copper for electrification; nickel plus rare commodities, such as lithium and cobalt for EV batteries; tellurium for solar panels; and neodymium for permanent magnets.

REE demand to grow at a 5% CAGR by 2030E – 272,000 mt.

We forecast global rare earth demand to grow at a 5% CAGR (to 272,000 metric tons by 2030), driven by clean energy applications.

However, supply growth is likely to be more restrained. China has adopted a comprehensive set of policies (e.g., export and production quotas and tax policies) that could limit supply growth, and projects outside China might not be able to fill the gap. The tight supply-demand situation should continue to support REEs and the related Rare Earth Oxide (REO) prices.

The growing demand for REEs bodes well for explorers and miners. Outside China, the two largest rare earths producing mines are owned by Lynas Rare Earths Limited (ASX: LYC) and MP Materials Corp. (NYSE: MP).

Catalysts

China supply controls; Acceleration of EVs; Solar panel and wind turbine demand – driven in part by global political decisions; Commercial company decisions; Rise of ESG investment criteria already applied by trillions of USD of institutional to retail AUM.

Rare Earth Elements – An Introduction

Rare earth elements are critical components of clean energy applications such as electric vehicles.

LREEs and HREEs - The rare earth elements (REEs) are a large family comprising 17 elements, including scandium, yttrium and the lanthanides, which can be sub-divided into light rare earth elements (LREEs), with atomic numbers 57-61, and heavy rare earth elements (HREEs), with atomic numbers 63-71. Light REEs include cerium, lanthanum, neodymium, praseodymium, samarium and scandium. Heavy REEs include yttrium, terbium and dysprosium.

Crustal abundance estimated for REEs at ~130 ug/g to 240 ug/g (150-220 ppm) – higher than most other commonly exploited elements.

Uses - **Light rare earth elements** (LREEs) are used in permanent magnets (electric vehicle motors, wind turbines) and advanced metal alloys, glass polishing and catalyst markets. **Heavy rare earth elements** (HREEs) and Yttrium are also used in magnets and are critical to defence applications.

REEs, although abundant in the Earth's crust, are difficult to mine economically.

Abundance - Rare earths, despite their name, are relatively abundant in the Earth's crust (~130-240 ug/g) but are difficult to mine because they are widely dispersed through the crust and are not often found in concentrations high enough to justify economic extraction. REEs do not exist as native metals due to their reactivity but occur in numerous ores and minerals. The **principal mined REE minerals** are **bastnaesite**, **monazite**, **loparite** and the **lateritic ion-absorption clays**.

Exhibit 1: **Rare Earth Elements (REEs) and commercial uses**

Element	Symbol	Application
		Light rare earths
Lanthanum	La	Rechargeable batteries, computer screens
Cerium	Ce	Polishing powders, glasses, ceramics
Praseodymium	Pr	Ceramics, glasses, pigments
Neodymium	Nd	Magnets for EV, consumer electronics
Promethium	Pm	Ceramics, glasses, pigments
Samarium	Sm	Magnets, nuclear industry
Europium	Eu	LCD screen, Bank notes
Scandium	Sc	Sports equipment, aerospace industry components
		Heavy rare earths
Gadolinium	Gd	LCD screens, medicine
Terbium	Tb	LCD screens, magnets
Dysprosium	Dy	Permanent magnets for electric vehicles and wind turbines
Holmium	Ho	Nuclear control rods, lasers
Erbium	Er	Glass, Lasers
Thulium	Tm	Lasers
Ytterbium	Yb	Portable X-ray machines, Lasers
Lutetium	Lu	Memory devices, catalyst, medicine
Yttrium	Y	Microwave filters, Phosphors

Sources: ACF Equity Research Graphics; US Geological Survey.
Notes: Scandium is the lightest of rare earths, but not classified as a LREE.

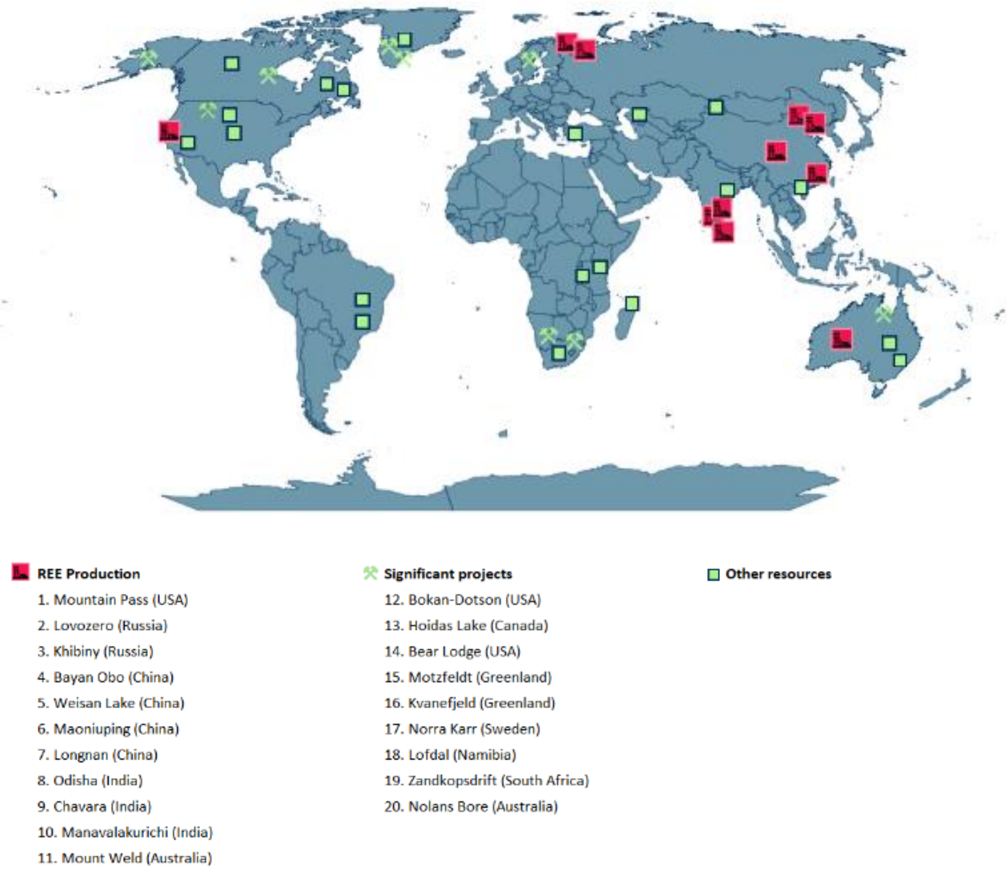
China controls ~90% of global REE production.

REE production is primarily concentrated in China and India (exhibit 2). China controls almost 90% of global REE production and India has the world's 5th largest reserves.

India is becoming a contender in the REE market.

The ongoing US-China geopolitical tensions and the globalised supply chains that have powered India's economic growth are making India a contender and a precious opportunity in the market. India could emerge as a global REE supplier and a high-end manufacturing economy.

Exhibit 2: **REE major deposits**



Sources: ACF Equity Research Graphics; Australian Bureau of Statistics; GeoNames; Microsoft; Navinfo; OpenStreetMap; TomTom; Wikipedia.

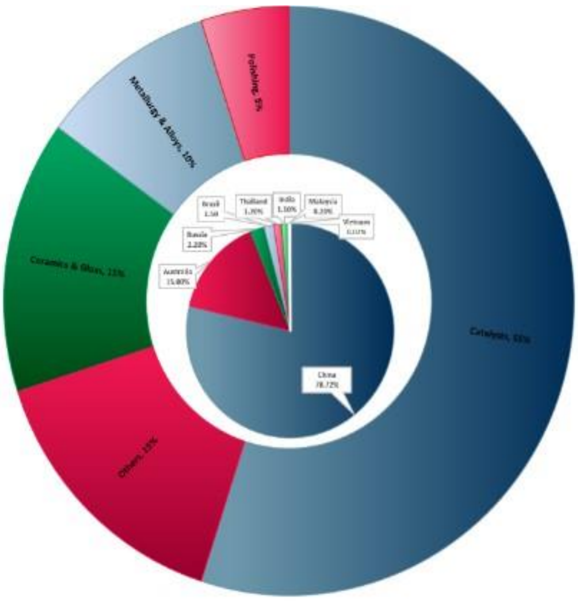
REEs are also used in military operations – fin actuators (heatsink for dissipation of heat from motors and power electronics), missile guidance, control systems, disk drive motors, satellite communications, radar and sonar systems.

Exhibit 3: **Important minerals associated with REE deposits**

Mineral	Formula
Allanite	$(Y,Ln,Ca)_2(Al,Fe^{3+})_3(SiO_4)_3(OH)$
Apatite	$(Ca,Ln)_5(PO_4)_3(F,Cl,OH)$
Bastnaesite	$(Ln,Y)(CO_3)F$
Eudialyte	$Na_4(Ca,Ln)_2(Fe^{2+},Mn^{2+},Y)ZrSi_8O_{22}(OH,Cl)_2$
Fergusonite	$(Ln,Y)NbO_4$
Gittinsite	$CaZrSi_2O_7$
Iimoriite	$Y_2(SiO_4)(CO_3)$
Kainosite	$Ca_2(Y,Ln)_2Si_4O_{12}(CO_3)\cdot H_2O$
Loparite	$(Ln,Na,Ca)(Ti,Nb)O_3$
Monazite	$(Ln,Th)PO_4$
Mosandrite	$(Na,Ca)_3Ca_3Ln(Ti,Nb,Zr)(Si_2O_7)_2(O,OH,F)_4$
Parisite	$Ca(Ln)_2(CO_3)_3F_2$
Pyrochlore	$(Ca,Na,Ln)_2Nb_2O_6(OH,F)$
Rinkite (rinkolite)	$(Ca,Ln)_4Na(Na,Ca)_2Ti(Si_2O_7)_2(O,F)_2$
Steenstrupine	$Na_{14}Ln_6Mn_2Fe_2(Zr,Th)(Si_6O_{18})_2(PO_4)_7\cdot 3H_2O$
Synchysite	$Ca(Ln)(CO_3)_2F$
Xenotime	YPO_4
Zircon	$(Zr,Ln)SiO_4$

Sources: ACF Equity Research Graphics; Dostal, 2017; Geoscience Frontiers Vol 10, 2019; V Balaram.

Exhibit 4: **REE regional sources and global uses**



Sources: ACF Equity Research Graphics; Namibia Critical Metals.

Supply of REEs - Production and Processing

China leads the global production of REEs, accounting for 57% of total production in 2020A.

China is currently the leading producer of REEs. The worldwide mine production of REEs in 2020 was estimated to be 240,000 Mt according to data from US Geological Survey. China accounted for nearly 57% of total production in 2020, followed by the US in the second place at 15% of production. For 2021, China set its rare earth mine output quota at 168,000 Mt, up 20% y/y.

We expect China's dominance to weaken.

We expect China's dominant position to weaken a little. We forecast China's share of total production will have fallen to below 50% by 2022A (once the data is assembled). Over the last five years or so, China's market share has decreased on average by a little over 5% each year, down from 81% in 2016 to 57-58% in 2020. A similar decline since 2020 would bring production below 50% by 2022A.

Exhibit 5: **Worldwide REE production and reserves (tonnes)**

Country	2019A Production	2020A Production	2020A Reserves	2020A % total reserves	Reserve classification
China	132,000	140,000	44,000,000	0.32%	M+I
Vietnam	1,300	1,000	22,000,000	0.00%	M+I
Brazil	710	1,000	21,000,000	0.00%	M+I
Russia	2,700	2,700	12,000,000	0.02%	M+I
India	2,900	3,000	6,900,000	0.04%	M+I
Australia	20000	17000	4,100,000	0.41%	M+I
United States	28,000	38,000	1,500,000	2.53%	M+I
Greenland	-	-	1,500,000	N/A	M+I
Tanzania	-	-	890,000	N/A	M+I
Canada	-	-	830,000	N/A	M+I
South Africa	-	-	790,000	N/A	M+I
Madagascar	4000	8000	N/A	N/A	M+I
Burma	25000	30000	N/A	N/A	M+I
Burundi	200	500	N/A	N/A	M+I
Thailand	1,900	2,000	N/A	N/A	M+I
RoW	66	100	310,000	0.03%	M+I
Total	**220,000**	**240,000**	**120,000,000**		

Sources: ACF Equity Research Graphics; US Geological Survey.

US dominated the REE industry in the 1940s.

Summary background to REE global production - In the 1940's, the United States dominated the REE industry in production and trading - in 1949, REEs were discovered at Mountain Pass, CA (dominated by Bastnaesite, an LREE fluorocarbonate mineral). The US, and Russia, were the leading superpowers and REEs were needed for nuclear weapons. Demand began to grow as new applications such as mischmetal, a rare earth alloy (e.g., used in the Alaskan oil pipeline).

China came onto the scene in the 1950s.

On the other side of the Pacific Ocean, the first record of rare earth deposits was discovered in Bayan Obo, Mongolia in 1927. By the 1950s the Chinese built a mine in Bayan Obo to recover REEs and proceeded to discover bastnaesite deposits in China from 1960-1980.

By the late 70s, China's global production of REEs rose to 40%/annum.

China dominates the REE market by the 1990s – government proclaims REEs as a "protected and strategic mineral".

Between 1978-1989, China was averaging an increase of 40% of annual production – making it the world's largest producer. In 1990, the Chinese government strategically proclaimed rare earths a "protected and strategic mineral". This put China's domination at the forefront of REE global production. This declaration opened opportunities for foreign investors to participate in joint ventures (JVs) with Chinese firms, even though foreign entities were prohibited from mining in China.

Light REEs vs. Heavy REEs - Rare earth elements are divided into two categories – light or heavy – based on atomic numbers (the number of the chemical element in the periodic table – referring to the number of protons found in the nucleus).

REEs with low atomic numbers, 57 to 62, are known as light rare earth elements (LREEs). Those with high atomic numbers, 63 to 71, are called heavy rare earth elements (HREEs). Scandium (38) is included in LREEs and Yttrium (39) is included in HREEs, because they have chemistries similar to their respective categories despite having their atomic numbers.

Exhibit 6: **LREEs vs. HREEs**

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
			Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
			Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Light rare earth elements (LREEs)

38 Sc -Scandium	57 La -Lanthanum	58 Ce -Cerium	59 Pr -Praseodymium	60 Nd -Neodymium	61 Pm -Promethium	62 Sm -Samarium	63 Eu -Europium

Heavy rare earth elements (HREEs)

39 Y -Yttrium	64 Gd -Gadolinium	65 Tb -Terbium	66 Dy -Dysprosium	67 Ho -Holmium	68 Er -Erbium	69 Tm -Thulium	70 Yb -Ytterbium	71 Lu -Lutetium

Sources: ACF Equity Research Graphics.

China accounts for 57% of the world's mined rare earths output and 85% of refined output (2020A).

Permanent magnets are the largest consumer of rare earth elements.

While **China's** share of **mine production is falling**, its share of processing and refining capacity to convert rare earth mine outputs in oxides, metals, alloys and magnets has continuously expanded. **Processing is a crucial step** in the supply chain, a step currently **still dominated by China**. China currently produces about 85% of the world's refined rare earths products, according to data from Australian Department of Industry, Science, Energy and Resources.

China's rare earth mining output is controlled by six state-run companies - China Minmetals Rare Earth Co, Chinalco Rare Earth & Metals Co, Guangdong Rising Nonferrous, China Northern Rare Earth Group, China Southern Rare Earth Group and Xiamen Tungsten. The mining quotas for each of these six firms for 2021 are given below.

Exhibit 7: **Chinese state mining firm's quota for 2021 in mt**

Company	2021E Production
China Northern Rare Earth Group	100,350
China Southern Rare Earth Group	42,450
Chinalco Rare Earth & Metals Co	17,050
Xiamen Tungsten	3,440
Guangdong Rising Rare Metals	2,700
China Minmetals Rare Earth Co	2,010
Total	**168,000**

Sources: ACF Equity Research Graphics; China Ministry of Industry and Information Technology.

REE Processing Procedure

The REE processing procedure involves several stages: mining, crushing, separation/flotation, purification and final product preparation.

Mining: Mining the rare earth-bearing minerals or ores from the ground. The ores are typically found in low concentrations and are often mixed with other minerals.

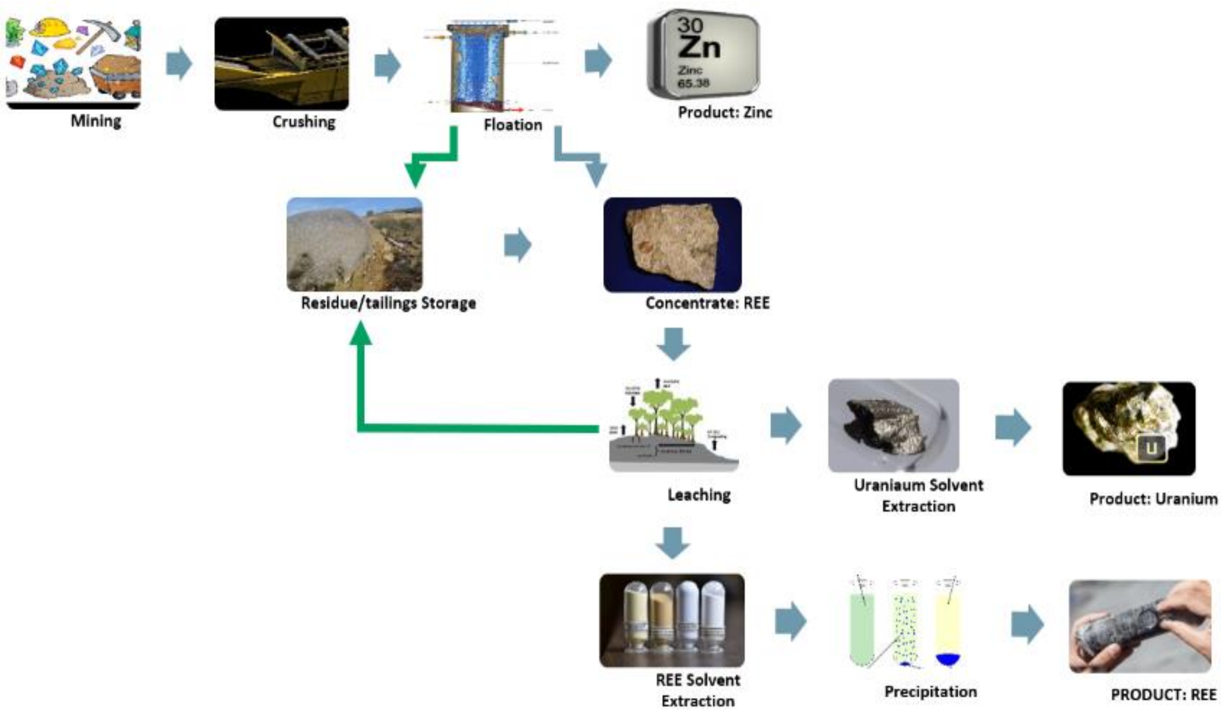
Crushing: Ores are crushed and milled into a fine powder. This process increases the surface area of the ores, making it easier to extract the rare earth elements.

Separation/flotation: Separating the REEs from the other minerals and impurities in the ore. This is done using chemical and physical separation techniques, including gravity separation, magnetic separation, and froth flotation.

Purification: After REEs are separated from the other minerals, they are purified to remove any remaining impurities, using solvent extraction/ion exchange techniques.

Final product preparation: The purified REEs are prepared for use in various applications via melting and casting into the desired shape or combining them with other materials to create alloys or compounds.

Exhibit 8: **REE processing procedure**



Sources: ACF Equity Research Graphics.

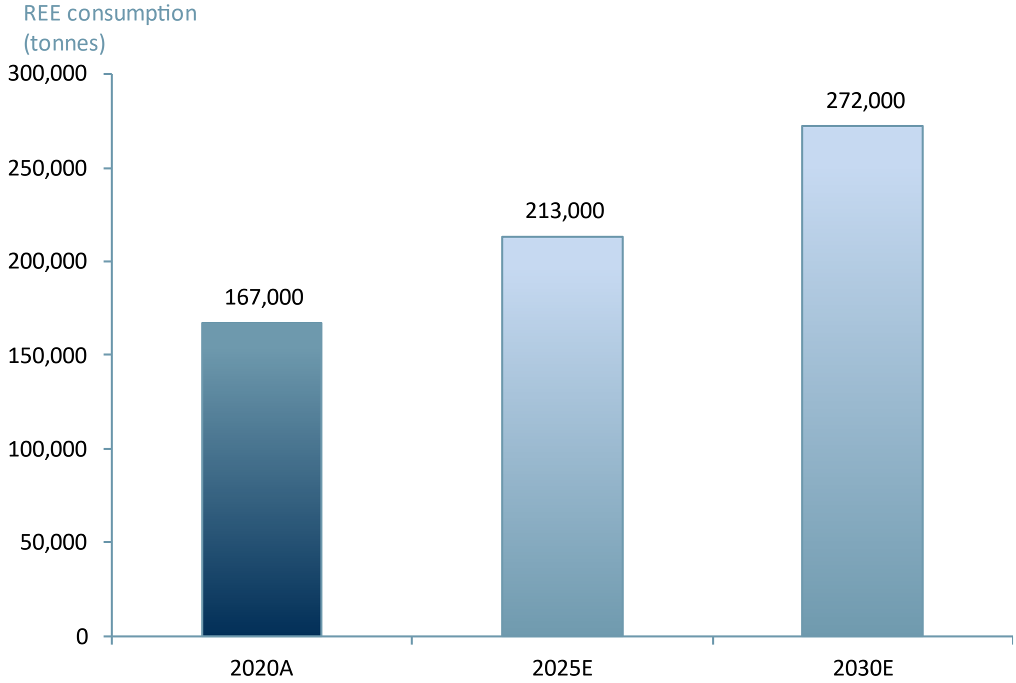
Demand for REEs

REE consumption has grown by ~3.9% p.a. between 2015-20.

ACF forecasts demand will grow at 5% p.a. through to 2030E.

From 2015-20, the consumption of rare earths has grown by an estimated 3.9% per year, according to the Australian Department of Industry, Science, Energy and Resources. We expect the demand to grow faster in the next decade driven by clean energy applications where REEs are critical components. Demand is forecasted to grow at 5% per annum until 2030 to nearly 272,000 Mt, vs. approximately 167,000 Mt in 2020 (as per Arafura Resources).

Exhibit 9: **Worldwide REE consumption forecast**



Sources: ACF Equity Research Forecast; Arafura Resources

REEs largest application is in magnets – used in wind turbines and EVs.

REEs largest consumption (demand) application is in magnets (for use in wind turbines, and electric vehicle motors), which accounted for 26% of total REE consumption in 2019, according to US Geological Survey.

REEs are also used in metal alloys, polishing and catalysts.

Magnet consumption is followed by metal alloys (for use in batteries, fuel cells) at 19% of total consumption, polishing (16.5%) and for catalysts used in oil refineries and automobiles (15.5%).

Exhibit 10: **Global consumption of REEs by application 2021A**

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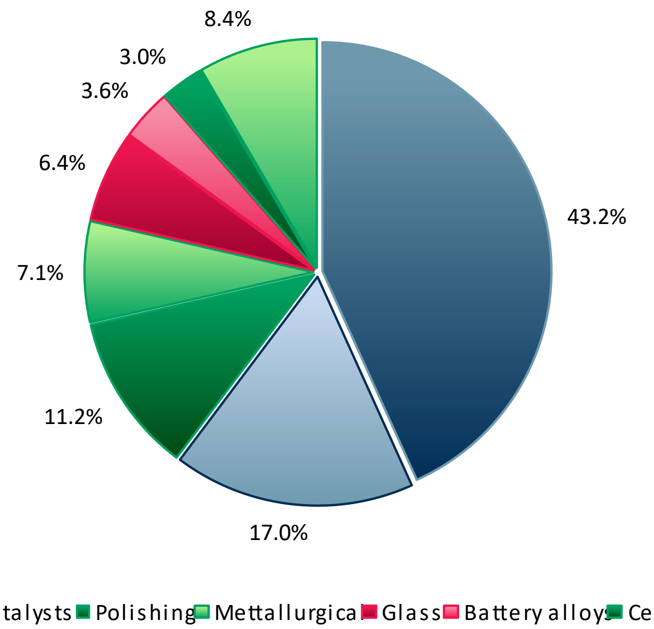


Sources: ACF Equity Research Graphics; Arafura Resources.

The substantial dependence on China, which accounts for more than 50% of world's rare earth production, makes other countries strategically vulnerable, especially if China decides to restrict exports to a particular country.

China's REE dominance is forcing other countries to diversify their supply chains.

The dominance of China within the rare earths market has forced many countries to look for ways to diversify their supply chains. This includes making direct investments locally to build rare earth mining projects.

Europe and North America have started to take tangible steps toward the buildout of resilient rare earths supply chains that depend less on China, but these efforts are still in their infancy.

Australia's government announces A$2bn loan facility to support its REE industry.

In 2021, the Australian government announced a A$2bn loan facility to support the rare earth elements industry. Some of the major companies involved in REE mining and processing projects outside of China are listed below in exhibit 9.

Despite major investments in the US, Australia and within the EU, developing an alternate supply chain capable of replacing or decreasing dependence in a meaningful way on China's extraction and production remains a significant challenge. Nevertheless, the US and EU have created government incentives to promote the domestic production of REEs.

• US incentives

US Reclaiming American Rare Earths (RARE) Act of 2021 allows for a tax deduction and supports the supply chain.

The US introduced the Reclaiming American Rare Earths (RARE) Act in April 2021. The bill amends the IRS Code of 1986, permanently allowing "a tax deduction for the mining, reclaiming or recycling of critical minerals and metals from the US". The bill also supports the development of the REE domestic supply chain – incl. "technology, manufacturing, energy, healthcare and medical devices, broadband, transportation and national defence."

In August of 2021, the US Congress introduced a second bill to promote the domestic production of rare earth magnets – the Rare Earth Magnet Manufacturing Production Tax Credit Act of 2021. The reason for the bill was to support the rare earth supply chain and promote the far away/hard to reach project sites.

US Congress passes second bill to provide a tax credit for all REE magnets produced domestically.

The bill provides a $20/kg tax credit for all REE magnets produced domestically. If all component rare earth material is produced or recycled in the US the credit goes up to $30/kg. For example, once a company is fully operational (e.g., USA Rare Earth and its Colorado magnet plant) producing 2,000 tonnes of REE magnets p.a., this would equate to ~$40-60m in tax credits/year.

• EU incentives

EU launches European Raw Materials Alliance (ERMA) in 2020 to promote "reliable, secure and sustainable access to raw materials".

In September 2020, the EU launched the European Raw Materials Alliance (ERMA) (part of an Action Plan on Critical Raw Materials) to promote the "reliable, secure and sustainable access to raw materials". The Action Plan aims to:

- Develop the EU's value chains and make them more resilient for industrial ecosystems;
- Lessen the EU's dependency on primary (extracted from the earth) critical raw materials;
- Strengthen the EU's national sourcing of raw materials;
- Diversify sourcing from third parties and improve international trade.

ERMA also works to support local REE magnet producers to compete with China.

ERMA is also expected to assist the EU in becoming a force in the REE magnet market, helping local producers compete with China. Proposals are thought to include low-cost financing and compensation for high costs of raw materials. (The specifics have not been released to the public).

Exhibit 11: Major companies with REE projects outside China

Company	MCAP (US$ m)	Project	Country	REE Ore		Mixed REE Concentrate		REE Separation	
				Current	Planned	Current	Planned	Current	Planned
MP Materials (NYSE:MP)	5,007	Mountain Pass	US	✓		×	✓	×	✓
Lynas Rare Earth (ASX:LYC)	3,958	Mt. Weld	Australia	✓		✓		✓	
Iluka Resources (ASX:ILU)	3,024	Jacinth-Ambrosia	Australia	✓		×	✓	×	✓
Energy Fuels Inc. (NYSE:UUUU)	805	White Mesa Mill	US	×	×	✓		×	✓
Australian Strategic Materials (ASX:ASM)	699	Dubbo	Australia	✓		×		×	
Arafura Resources (ASX:ARU)	310	Nolans Bore	Australia	✓		✓		×	✓
Neo Performance Materials (TSX:NEO)	144	Sillamae	Canada	×	×	×	×	✓	
Texas Mineral Resources (OTCQB:TMRC)	90	Round Top	US	×	✓	×	✓	×	✓
Rare Element Resources (OTCQB:REEMF)	58	Bear Lodge	US	×	✓	×	✓	×	✓
Ucore Rare Metals (TSXV:UCU)	51	Bokan-Doston Ridge	Canada	×	✓	×	✓	×	✓

Sources: ACF Equity Research Graphics; Company Reports.

Exhibit 12: Trailing REE peer group metrics (Large / Small-Mid Caps)

TTM Metrics / Company Name	Market	Tkr	MCAP US$(m)	EV US$(m)	EV / REVS	EV / FCF	RoA	RoE
Lynas Rare Earths	**XASX**	**LYC**	**4,140.40**	**3,365.28**	**3.66x**	**50.64x**	**0.19**	**0.40**
MP Materials	XNYS	MP	3,824.11	3,497.89	10.05x	N/M	0.10	0.25
Iluka Resources	XASX	ILU	3,094.73	2,791.75	2.60x	9.89x	0.16	0.30
Energy Fuels	XNYS	UUUU	805.00	731.37	58.42x	N/M	-0.10	-0.22
Arafura Resources	XASX	ARU	627.39	545.00	N/M	N/M	-0.16	-0.26
Average					**18.68x**	**30.27x**	**3.78%**	**9.27%**
Median					**6.85x**	**30.27x**	**9.93%**	**24.90%**

TTM Metrics / Company Name	Market	Tkr	MCAP US$(m)	EV US$(m)	EBITDA US$(m)	Gross Debt / to Equity	RoA	RoE
Neo-Performance Mater.	**XTSE**	**NEO**	**298.81**	**201.32**	**75.61**	**10**	**0.06**	**0.06**
Australian Strategic Mater.	XASX	ASM	116.59	81.19	-19.23	8	-0.08	-0.13
Texas Mineral Resources	OTCM	TMRC	65.81	63.97	-3.07	N/M	-0.49	-0.82
Ionic Rare Earths	XASX	IXR	65.09	66.38	-3.60	0	-0.11	-0.17
Rare Element Resources	OTCM	REEMF	57.38	333.86	-9.36	2	-0.26	-0.47
Rainbow Rare Earths	XLON	RBW	51.16	49.79	-2.97	6	-0.12	-0.22
Ucore Rare Metals	XTSX	UCU	40.59	-173.03	-3.33	11	-0.06	-0.12
Average							**N/M**	**N/M**
Median							**N/M**	**N/M**

Sources: ACF Equity Research Graphics; Refinitiv.

Permanent Magnets

Most important rare earths used in permanent magnet production include Neodymium (Nd), Praseodymium (Pr) and Dysprosium (Dy).

Permanent magnets are the largest consumers of REEs. According to Rainbow Rare Earths (RBW.L), permanent magnets accounted for over 90% of the total value of rare earth oxide (REO) consumption in 2019.

Permanent magnets are materials where the magnetic field is generated by the internal structure of the material itself. A permanent magnet has a magnetic field which is **'always on,'** while an electromagnet is made from a coil of wire wrapped around a ferrous core and requires an electric current to generate a magnetic field. **Electromagnets are temporary** as they lose their magnetic ability once the electric current stops.

There are **four main categories of permanent magnets**: ceramic (also called ferrite), AlNiCo, Samarium Cobalt (SmCo) and **Neodymium Iron Boron** (NdFeB).

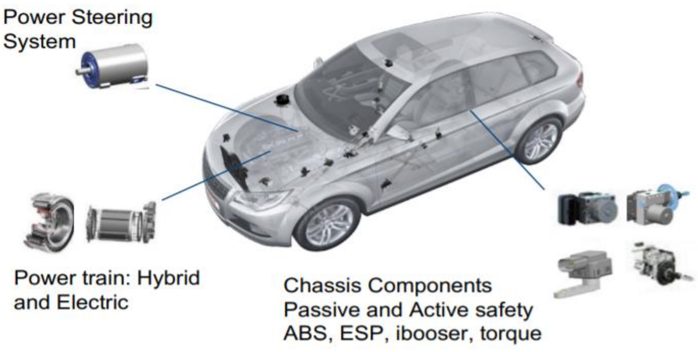
Of these, **NdFeB makes the strongest magnets**. They contain the following REEs - neodymium (Nd), praseodymium (Pr) and dysprosium (Dy). Neodymium is the main element used in the production of NdFeB permanent magnets, however they often contain praseodymium because the two are difficult to separate.

Neodymium and praseodymium as mixed oxides (NdPr oxide) are typically considered the main components of permanent magnets, which are critical in many so-called high-tech products, including electric vehicles, renewable energy wind turbines, consumer electronics et al.

NdFeB permanent magnets are most used in traction motors for hybrids and EVs.

NdFeB permanent magnets are most commonly found in traction motors for hybrids and EVs. Additionally, permanent magnets are used in power steering systems, chassis components and Anti-lock Braking System (ABS), amongst other applications.

Exhibit 13: **Use of permanent magnets in EVs**

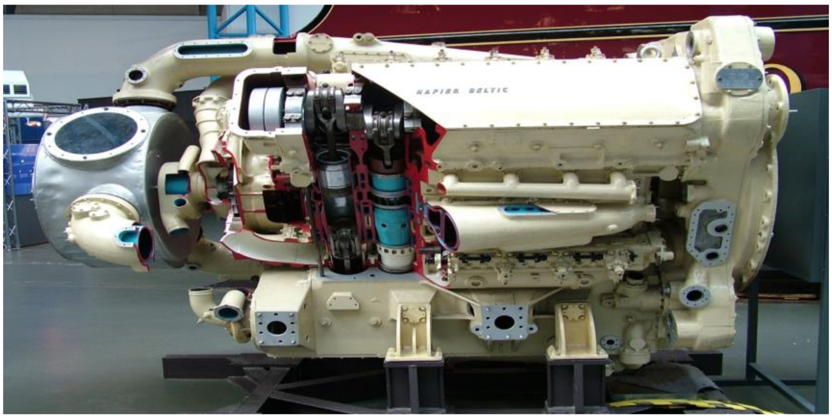


Sources: ACF Equity Research Graphics; Lynas Metals.

Traction motors are designed with high torque and low-speed characteristics.

In EVs, traction motors are used to convert electrical energy from the vehicle's battery/power source into mechanical energy that drives vehicle components. Traction motors are designed with high torque and low-speed characteristics to provide power and torque to move and accelerate heavy loads.

Exhibit 14: **Traction motor**



Sources: ACF Equity Research Graphics; CC BY-SA.

The traction motor generates the power to rotate the wheels of the vehicle. These motors are designed to work in relatively challenging operating conditions and provide high levels of efficiency, reliability and durability.

2.5m EVs were sold globally in 2020A.

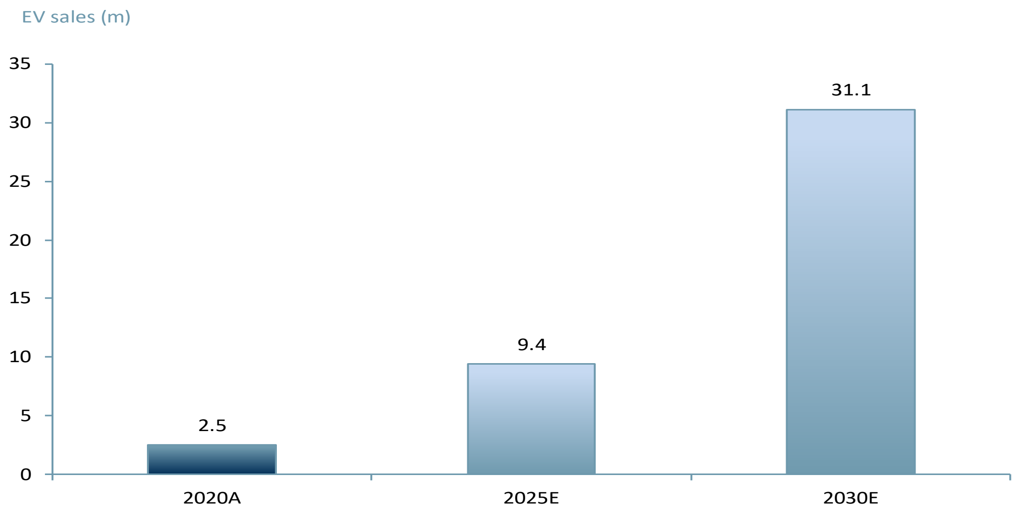
In 2020A, 2.5m new EVs with their traction motors were sold globally, according to data from the International Energy Agency (IEA) (exhibit 15). ACF projects the global EV market will grow to reach a value of $2,404bn by 2023E, implying a CAGR of 37.6%.

Rising demand for electric vehicles to reduce CO_2 emissions is expected to propel the use of permanent magnets in the production of EVs. This is because motors with rare earth permanent magnets have less mass and are less bulky than ferrite based permanent magnets, which in turn improves lithium-ion battery 'efficiencies.'

Tesla (Nasdaq:TSLA) said in an investor presentation 1Q23 that it had found an alternative solution to REE permanent magnets and that it intended to return its entire fleet to AC induction motors (Nicola Tesla invented the AC induction motor) as opposed to using REE permanent magnet motors in some models.

TSLA has been claiming that it has managed to reduce the amount of REE in its traction motors in its Tesla Model 3. TSLA also started suggesting in 1Q23 that it had found an alternative permanent magnet that does not use REEs.

Exhibit 15: **New Electric Vehicle (EV) sales**



Sources: ACF Equity Research Estimates; IEA.

For volume production of EVs the obvious alternative to REEs in a permanent magnet is ferrite, with additive elements. Other innovations are still far away from being able to support volume production of a product like an EV.

We maintain that accelerated expansion of vehicle electrification will drive demand for NdPr oxide and NdFeB magnets. Additionally, green power generation from direct drive wind turbines and other industrial and defence uses will drive REE demand.

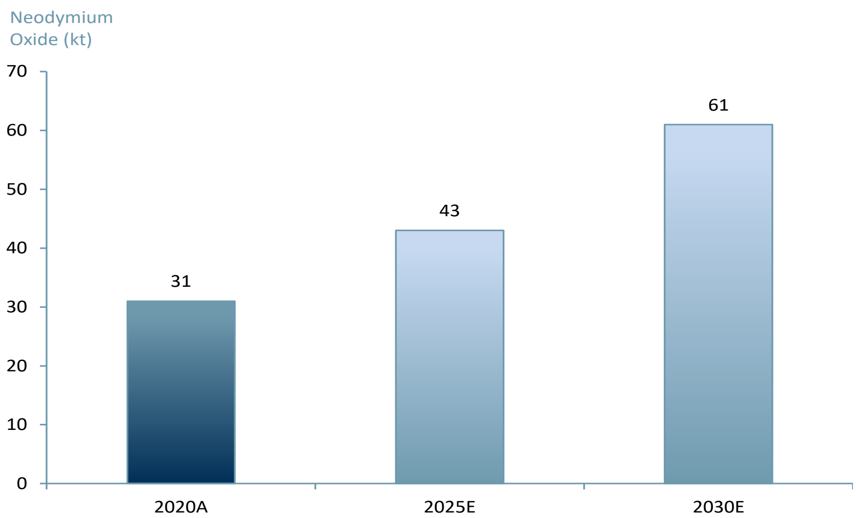
Direct drive wind turbine systems do not require a gearbox. A gearbox is often subjected to failure because of transmission losses and requires higher maintenance. The absence of a gearbox makes direct drive turbines more efficient. Permanent magnets are used in direct drive turbine system generators. Permanent magnet powered generators reduce turbine system weight and improve efficiency.

Arafura Resources notes that each EV uses an additional 1 Kg of NdPr per electric drive motor, while wind turbines use nearly 250 Kg of NdPr per MW of wind power generation. This implies a significant ramp up in demand for NdPr as governments and companies step up efforts to cut carbon emissions.

ACF's forecast is based on the following: IEA expects 5.7% CAGR till 2030, Mineral Council of Australia expects 7.8% CAGR and Roskill estimates 5.4% CAGR in demand. We assume a 7% increase in demand till 2030 = Kt in 2030 from 31 kt in 2020.

We forecast a positive demand outlook for magnet elements (mainly neodymium, praseodymium, dysprosium). In particular, we forecast demand for neodymium to almost double from 31 kt in 2020 (IEA) to approximately 61 kt in 2030E, implying a CAGR of 7%, which is higher than the demand forecast for the overall REE market.

Exhibit 16: **Neodymium Oxide demand forecast**



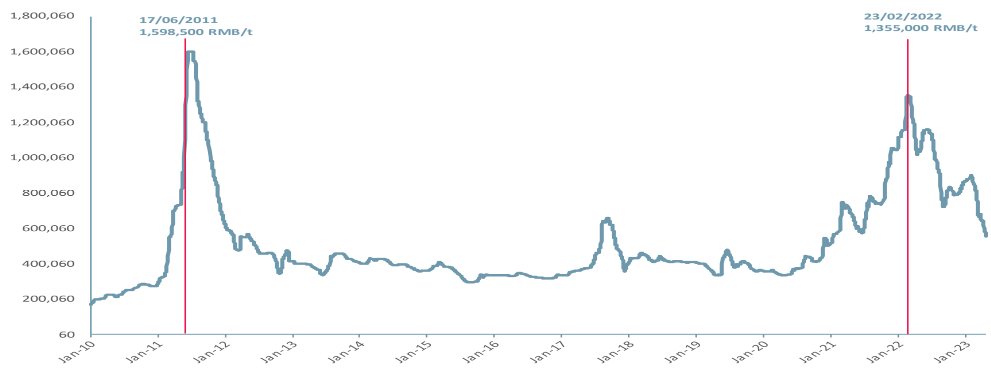
Sources: ACF Equity Research Forecast; IEA

The demand for NdPr oxide is set to grow exponentially over the next decade. The total demand for NdPr oxide was estimated at 55.5K Mt in 2020. We estimate demand to reach 125.5K Mt by 2030, growing at a CAGR of 8.5%.

In contrast, supply is unlikely to grow at our CAGRs given the significant development time involved in proving and setting up new mine capacity. We expect the supply deficit to continue for an extended period of time and to worsen before it improves, which in turn ought to support NdPr prices that are already touching decade highs.

The price for NdPr spiked to 1,355,000 yuan (or $119,403/Mt) on 23 Feb 2023, according to data from Shanghai Metals Market (exhibit 17).

Exhibit 17: **NdPr price 2010-2023**



Sources: ACF Equity Research; SDM Magnetics; Asian Metal.

How China Came to Dominate Permanent Magnets

China is the world's largest producer of permanent magnets, ~90% of global production.

How China became dominant is instructive. As with the overall REE market, China dominates the permanent magnets market. China is the world's largest producer of REE permanent magnets, accounting for ~90% of global production.

China began dominating the permanent magnet in the 1980s.

China's domination of the magnet market began in the 1980s when the Neodymium-Iron Boron (NdFeB) magnet was introduced. General Motors (NYSE:GM) and Hitachi (TYO:6501) both took out patents on NdFeb – GM on the 'rapidly solidified' / bonded magnet and Hitachi on the 'sintered' magnet. (Sintered and bonded differ based on BH (max), the amount of magnetic energy stored in the magnet material, 50M (magnetization) for sintered versus <10M for bonded).

Sintered magnets are made from a powder mixture of REEs and iron, pressed into a mould and heated to a high temperature. Sintered magnets have high magnetic strength, good resistance to demagnetization and therefore are used in applications that require high magnetic performance, e.g., motors, generators and speakers.

Bonded magnets are made by mixing magnetic powder with a binder material (plastic, resin, rubber), pressed or injected into a mould. Bonded magnets have a lower magnetic strength, are less brittle and easier to machine. They are used in applications that require complex shapes/ sizes, e.g., sensors, actuators and magnetic assemblies.

GM created a company – Magnequench – in 1983 to produce magnets for its cars. US investment firm Sextan Group, Inc. and two Chinese companies – Beijing San Huan New Material High-tech, Inc. & China National Non-Ferrous Metals Import & Export Corporation – acquired Magnequench in 1995.

Following the US government's deal with China in 1995, China shut down its US operations and moved the entire business to China.

The deal was approved by the US government under the stipulation that the company keep its operations in the US for at least five years. The day after the deal expired, Magnequench shut down its US operations and moved the entire business to China.

By 1998, the US only accounted for 15.63% of REE magnet production.

The Chinese took all their technology with them. In 1998, 90% of magnet production was based in the US, EU and Japan – as of 2020A China accounts for 57.57% of global REE production and the US only 15.63% (USGS).

Today, there is limited to no production of REE permanent magnets in the US.

Currently, US based production-scale capacity for rare earth permanent magnets could generously be described as limited. The remaining global NdPr magnet production outside of China is found primarily in Japan or Japanese-aligned facilities elsewhere in Asia, particularly in Vietnam, Philippines, and Thailand.

Centres of Permanent Magnet Trade

Exhibit 18: **Permanent magnet production centres in 2023**

Sources: ACF Equity Research Estimates; IEA.

Key Ports - REE magnets and ores are shipped to the key ports listed below depending on the origin and destination of the shipment.

- Port of **Hong Kong, China** - is a major shipping hub for REE magnets and ores in Asia and serves as a gateway to mainland China and other countries in the region.
- Port of **Shanghai, China** - is one of the busiest ports in the world and a key hub for REE trade, particularly for shipments from China.
- Port of **Singapore, Asia** - is a major transhipment hub for REE trade in Asia, serving as a key port for shipments to and from other countries in the region.
- Port of **Busan, South Korea** - is the largest port in South Korea and a key hub for REE shipments in Asia, particularly for shipments to and from Japan.
- Port of **Los Angeles, US** - is one of the largest ports in the United States and a major entry point for REE shipments into North America.
- Port of **Rotterdam, Europe** - is the largest port in Europe and a key gateway for REE shipments into the European market.

Glossary

AUM	Assets Under Management – total market value of the investments/financial assets that an individual or financial institution manages on behalf of investors.
CAGR	Compounded annual growth rate - the mean annual growth rate of an investment over a specified period.
CO_2	Carbon dioxide - a gas that occurs naturally. It is a chemical compound that consists of one carbon and two oxygen atoms.
COP26	United Nations Climate Change Conference - held in Glasgow in November 2021 by governments across the world.
Dy	Dysprosium - a rare earth element with a metallic silver lustre.
EV	Electric vehicles - vehicles which are powered by electric motors rather than internal combustion engine.
HREEs	Heavy rare earth elements – rare earth elements with atomic numbers 63-71.
IEA	International Energy Agency - an autonomous agency with the objective of improving the world's energy supply and demand infrastructure.
Lanthanides	The lanthanide series of chemical elements comprises the 15 metallic chemical elements with atomic numbers 57–71. Along with scandium and yttrium, they make up the rare earth elements.
LREEs	Light rare earth elements – rare earth elements with atomic numbers 57-61.
MW	Megawatts – measures the output of a power plant or the amount of electricity required to generate power.
Nd	Neodymium - it belongs to the lanthanide series and is a rare earth element. It is a hard, slightly malleable, silvery metal that quickly tarnishes in air and moisture.

NdFeB	Neodymium Iron Boron magnets - a permanent magnet made from an alloy of neodymium, iron, and boron.
Pr	Praseodymium - a soft, silvery, malleable and ductile metal, valued for its magnetic, electrical, chemical, and optical properties.
REEs	Rare Earth Elements - the group of 17 elements known for their unique physical and chemical properties.
REO	Rare Earth Oxides – are also known as rare earth elements. They are referred to as REOs because many of them are sold as oxide compounds.
USGS	United States Geological Survey – a US government scientific agency that studies the landscape of the US, its natural resources and the natural hazards that threaten its natural resources.

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Head of Research
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