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Critical Raw Materials: Redefining for green energy

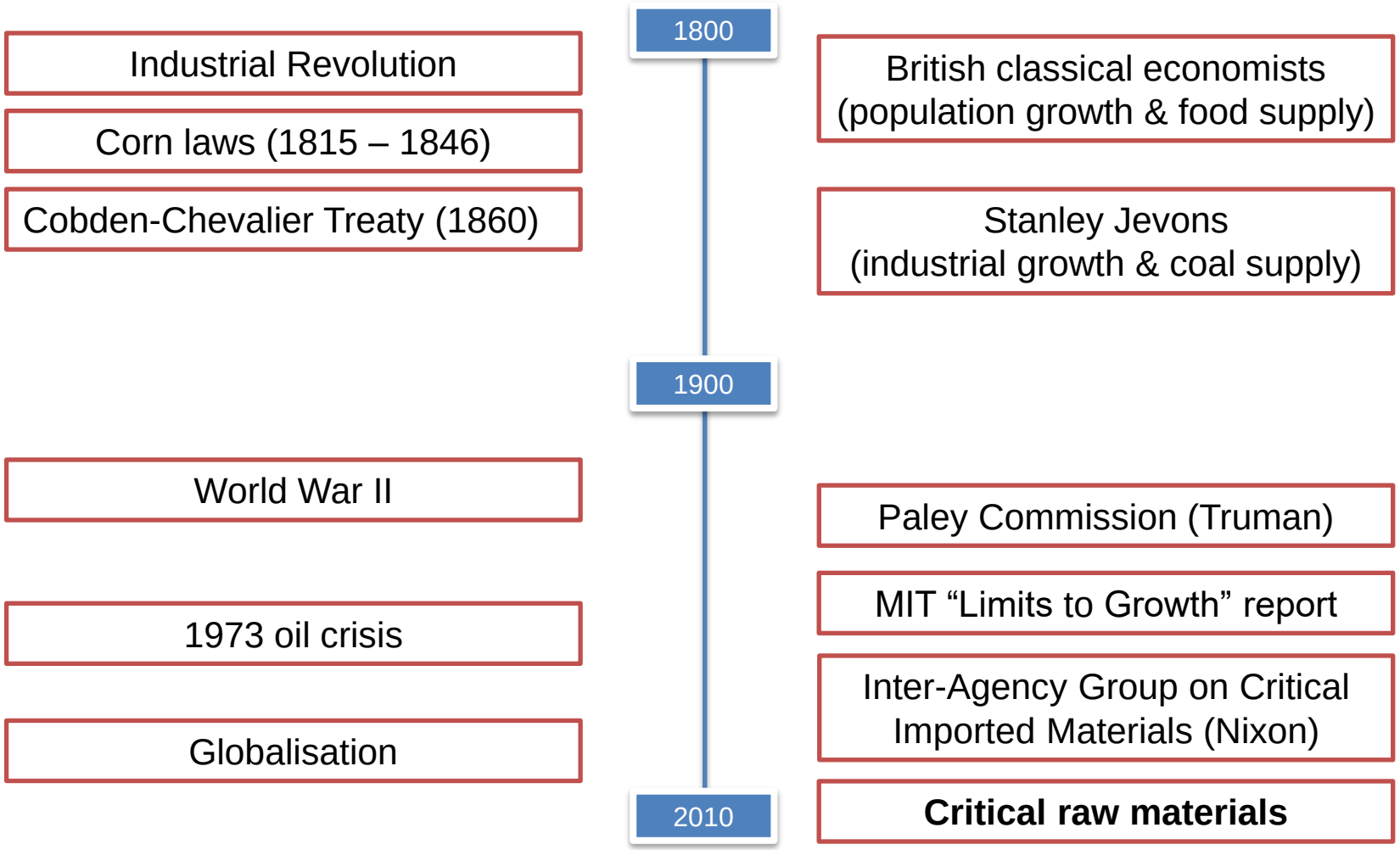
Association of Mining Analysts

January 2017

‘Critical raw materials’

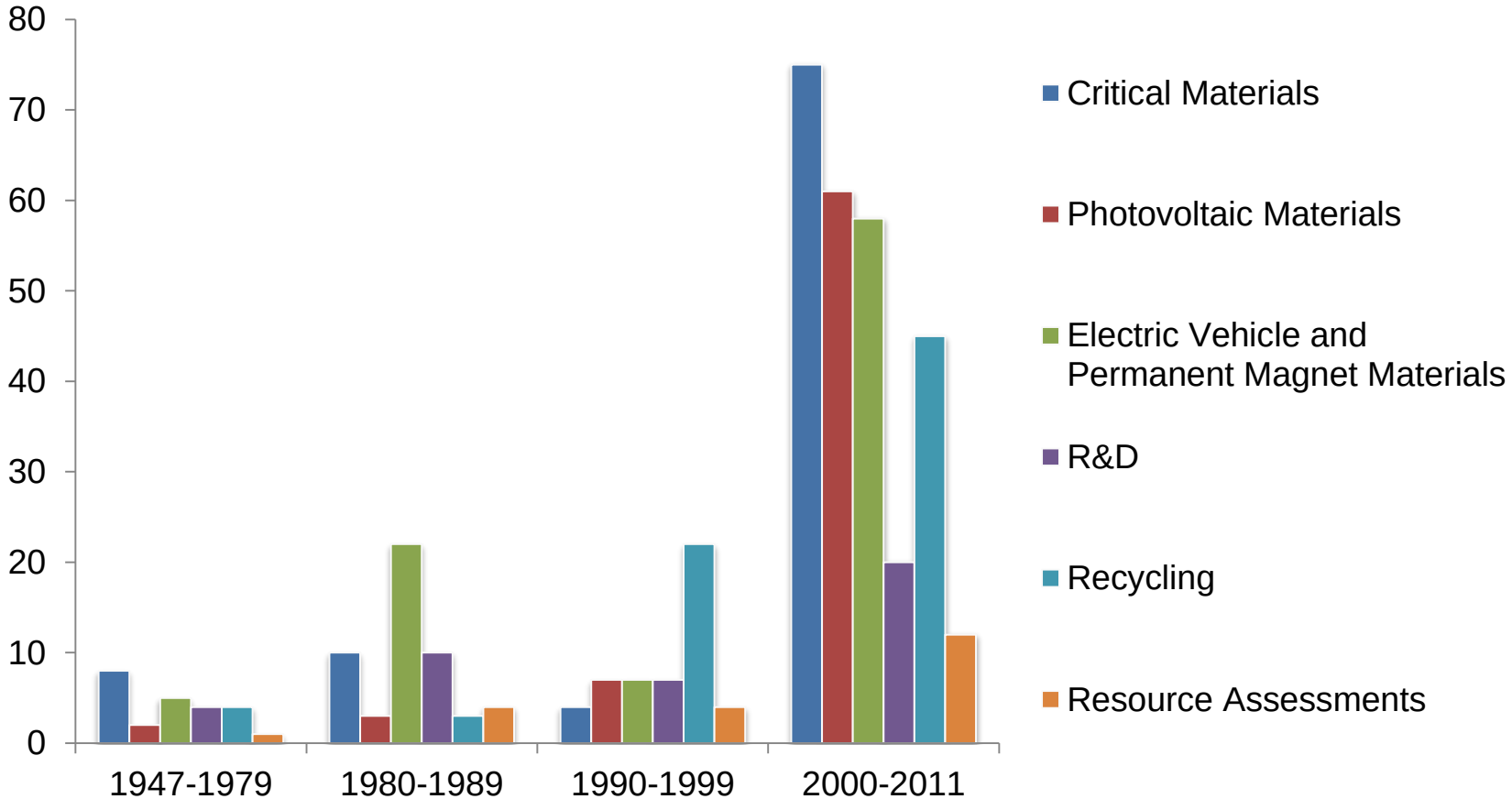
…materials which are of high economic importance to a particular industry, sector or spatial area, and are at risk of supply shortage…

CRM timeline: The discourse on resource scarcity has evolved over time…



CRM focus: There has been a glut of critical raw materials studies since 2000, aligned with a change in world order

Number of published papers on material availability by topic

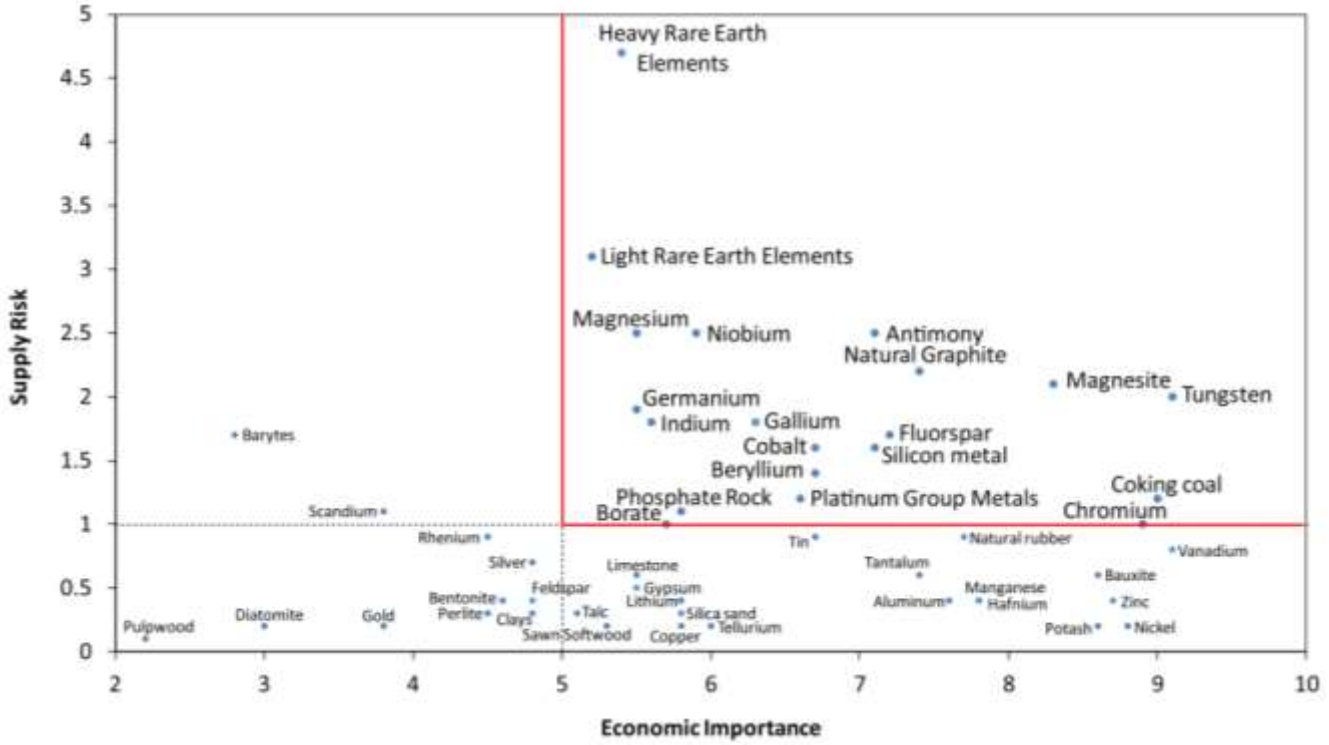


Source: Results obtained based on a systematic review of the available literature on materials availability, following the systematic review process utilised by the UK Energy Research Centre (UKERC) Technology and Policy Assessment (TPA) theme

CRM studies: Europe and US have been the main drivers of research

Date	Organisation	Report
2007	US National Research Council	Minerals, critical minerals, and the US economy
2009	UNEP	Critical Metals for Future Sustainable Technologies & their Recycling Potential
2010	European Commission	Critical raw materials for the EU. Report of the ad–hoc working group on defining critical raw materials
2010	US Department of Energy	Critical materials strategy
2010	German Federal Ministry of Economics and Technology	The German Government's Raw Material Strategy - Safeguarding a sustainable supply of non-energy resources for Germany
2012	British Geological Survey	Risk List 2012

EU CRM study: Most commentary on CRMs uses the EU CRM studies of 2011 and 2014 to define criticality



- **Economic importance -** the proportion of each material associated with industrial mega sectors such as construction, combined with its gross value added to EU GDP. This total is scaled according to total EU GDP to define the overall economic importance of a material.

- **Supply risk -** the World Governance Indicator (WGI) is used to measure the supply risks of raw materials. This indicator takes into account accountability, political stability and absence of violence, government effectiveness, regulatory quality, and rule of law.

Source: Roskill

‘How to tackle potential supply shortage’

…diversify supply, develop substitutes and improve recycling…

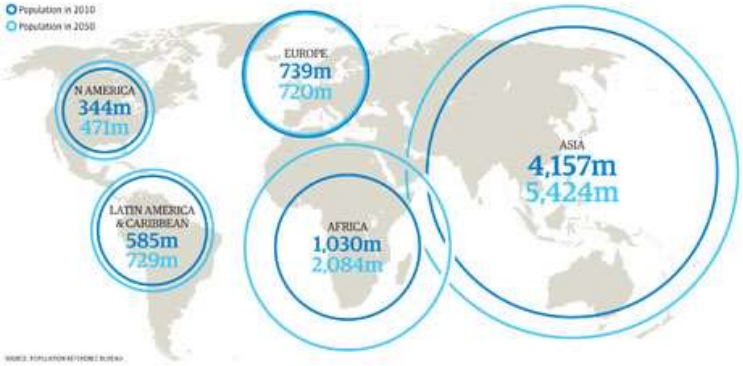
= policies and money in place to achieve the last two, but first still to be tackled

“Green” CRMs

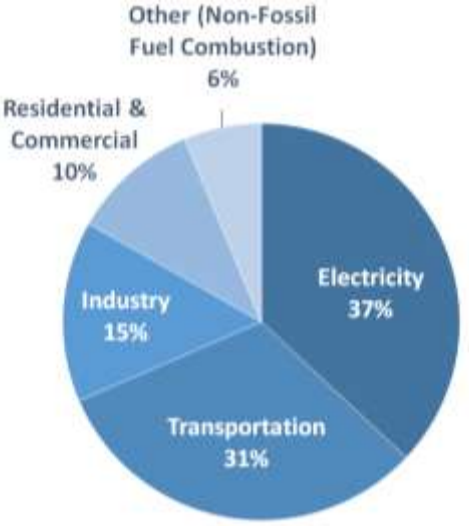
Moving the goalposts: reassessing what defines future economic importance

- Global trends dictating raw material use:
  - Population growth: Africa
  - Increasing affluence: Asia
  - **Energy efficiency: Global**
  - **CO_2 emission reduction: Global**
- Overall, demands for raw materials will continue
- But how to achieve the last two…
- Mitigating technologies:
  - Products and processes saving raw materials, energy and CO_2 emissions during manufacturing
- Enabling technologies:
  - Products and processes saving CO_2 emissions during use

Global population growth 2050



Main sources of CO_2 in the US



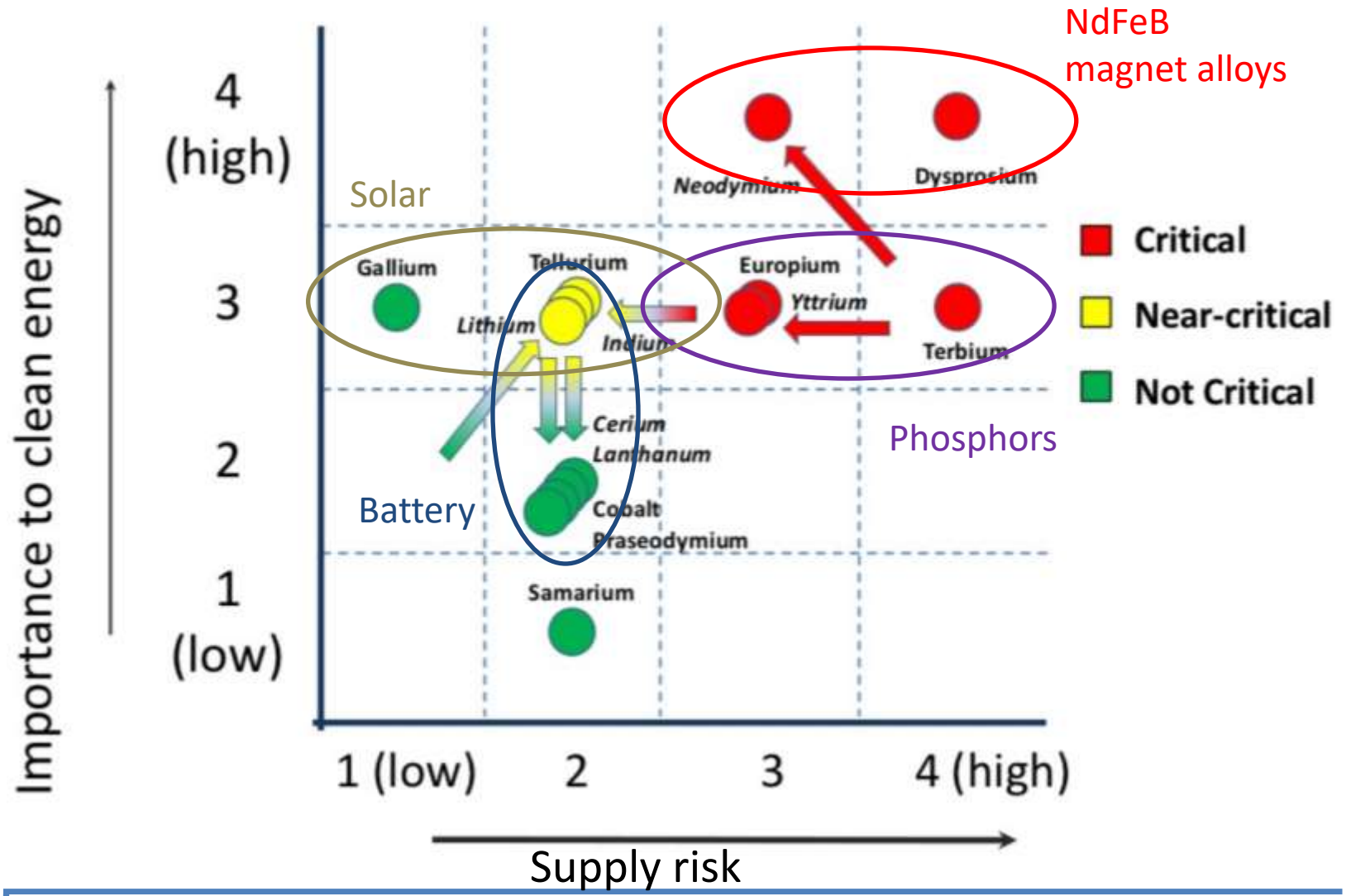
Source: AMG; Roskill

DoE CRM study: More relevant to CO_2 reduction is the DoE's CRM study focused on materials critical to "clean" energy

Technology	Component	Material	Intensity of use
Electric vehicles	Motor/generator	Neodymium	0.31-0.62kg/unit
		Dysprosium	0.06-0.11kg/unit
	NiMH battery	REE Mischmetal (La)	1.5-2.2kg/unit
		Cobalt	0.44-0.66kg/unit
	Li-ion battery	Cobalt	0-9.4kg/unit
		Lithium	1.4-12.7kg/unit
Wind turbine	Generator	Neodymium	124-186kg/MW
		Dysprosium	22-33kg/MW
Photovoltaics	CIGS	Indium	16.5-110kg/MW
		Gallium	4-20kg/MW
	CdTe	Tellurium	43-145kg/MW

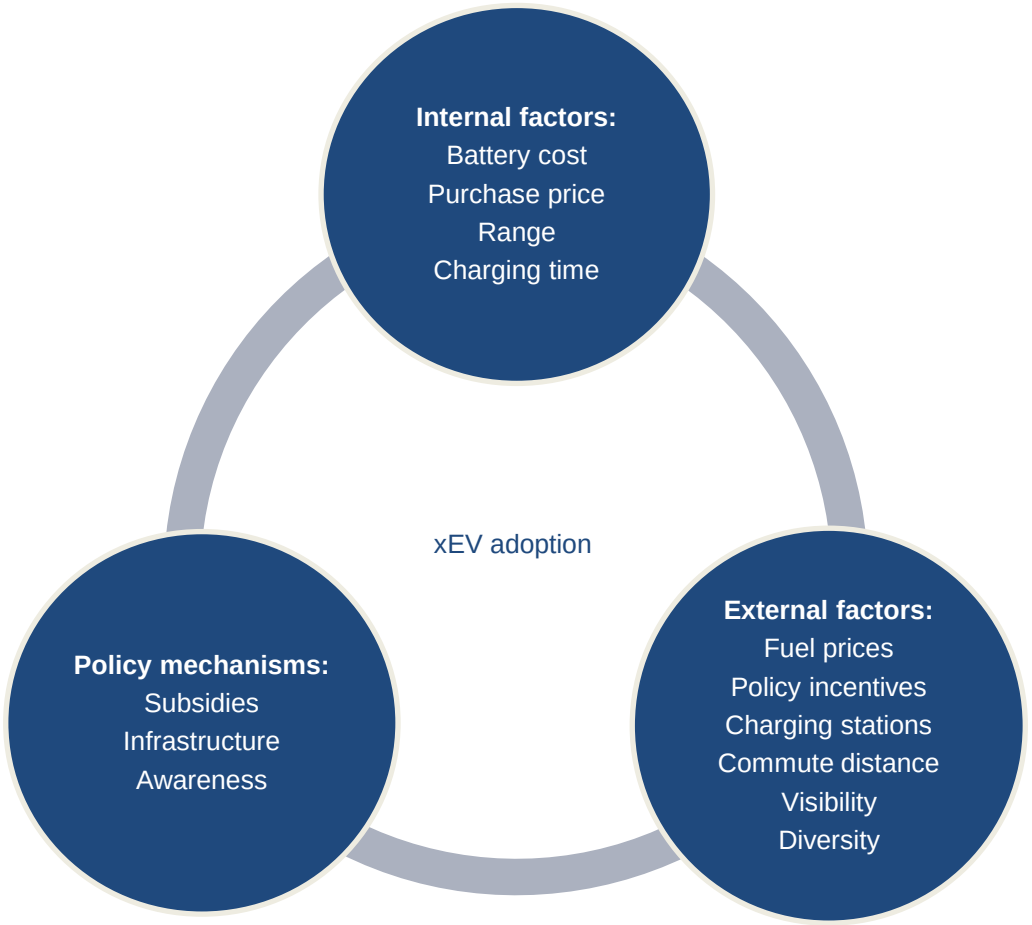
Source: US DOE, Roskill
Note: Elements for phosphor applications removed as lighting industry now concentrating on LEDs

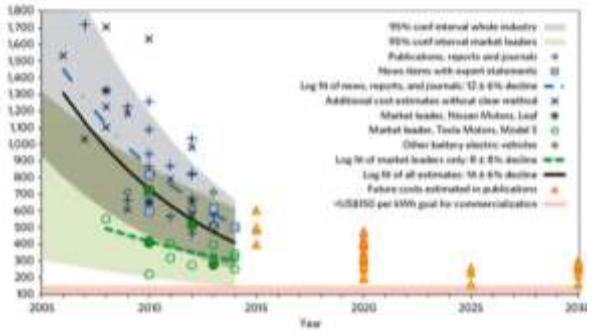
DoE CRM: Identified REEs Nd & Dy as critical; indium and tellurium near-critical, and lithium moving to near-critical

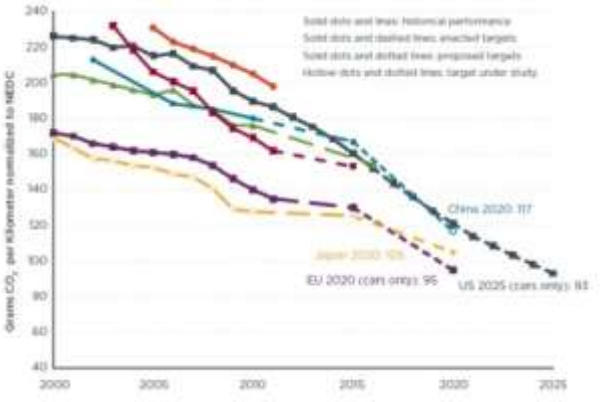


Source: US Department of Energy, 2011

xEV: Adoption is limited by internal, external and other factors; a combination is needed to achieve success

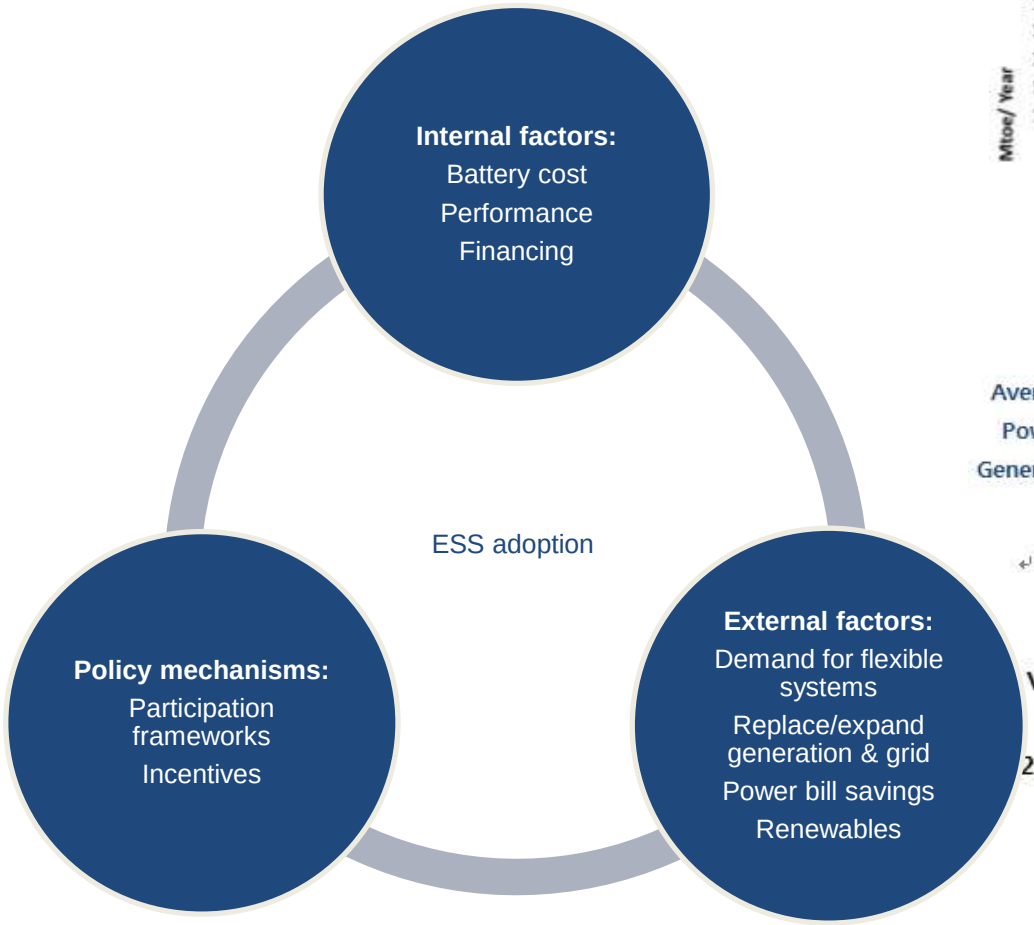


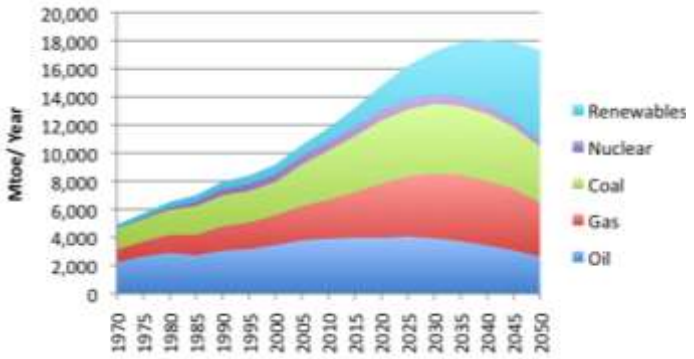


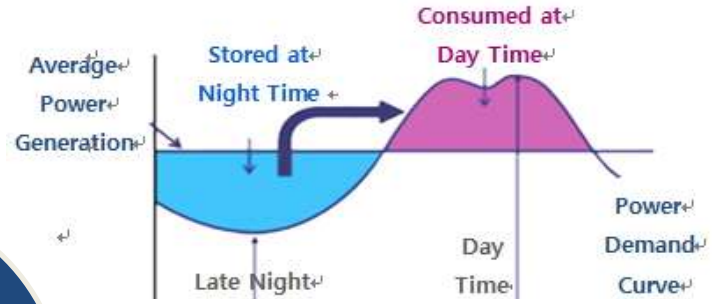


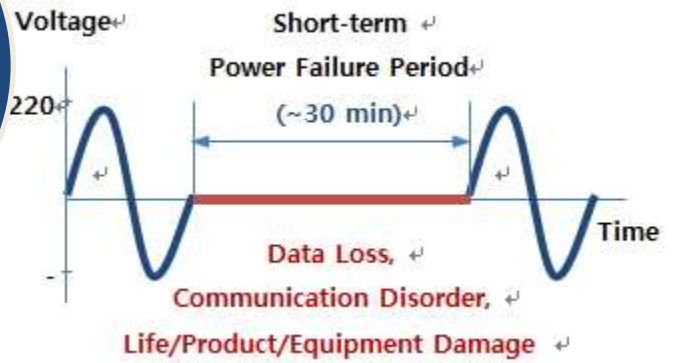
Source: Various

ESS: Market is growing with renewables and needs of an old and unstable grid



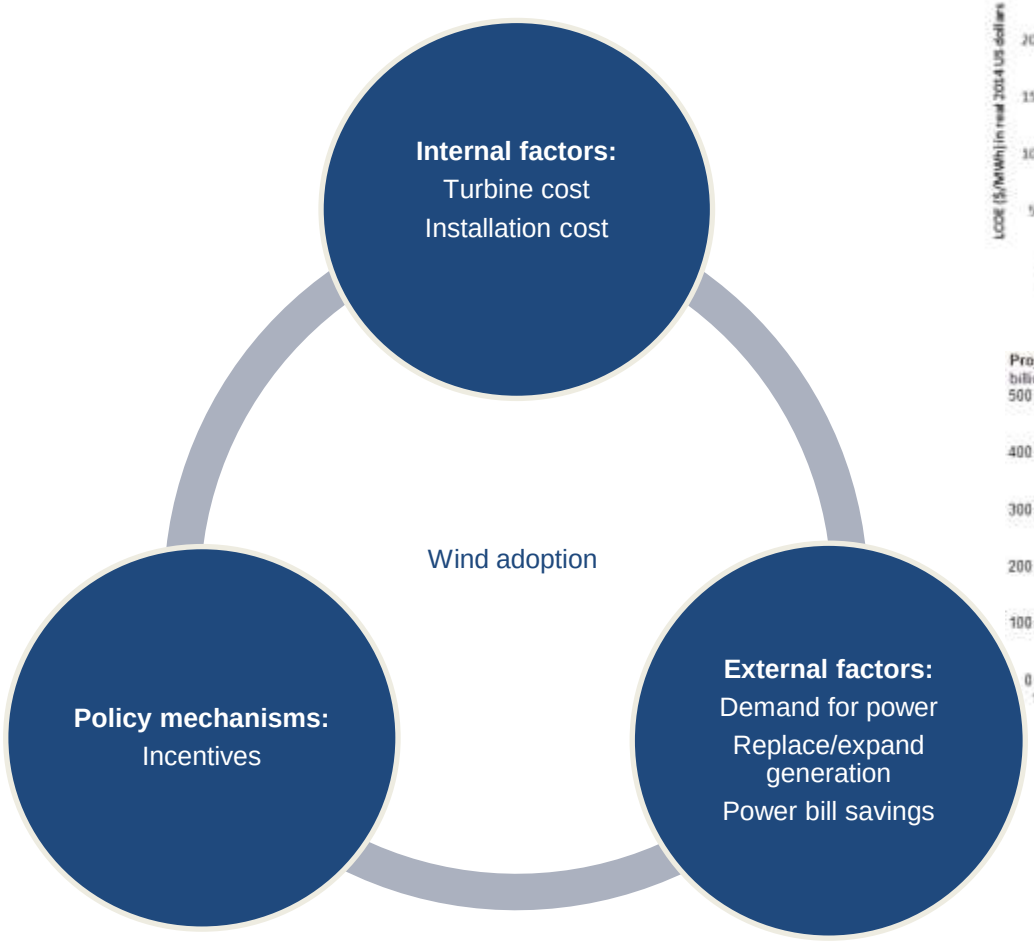


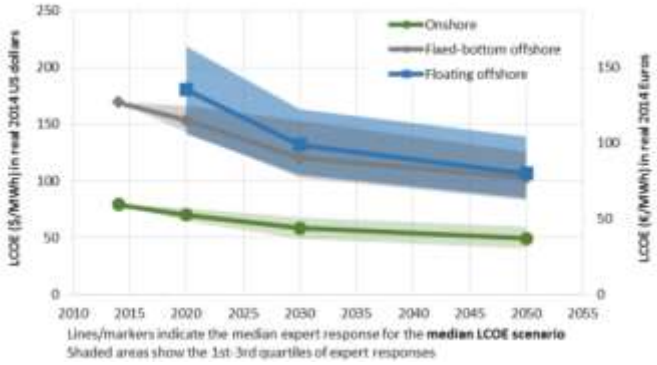


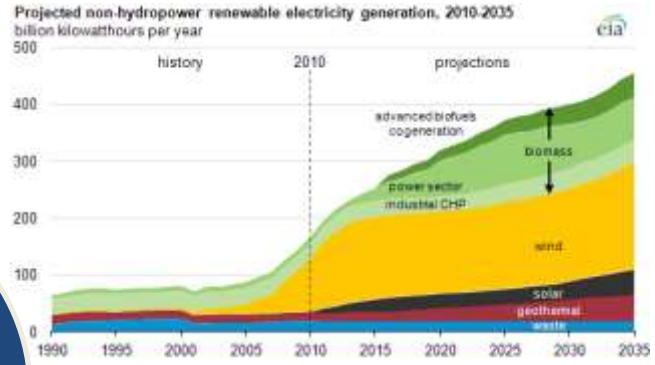


Source: Various

Wind: Market is growing with renewables and needs of an old and unstable grid



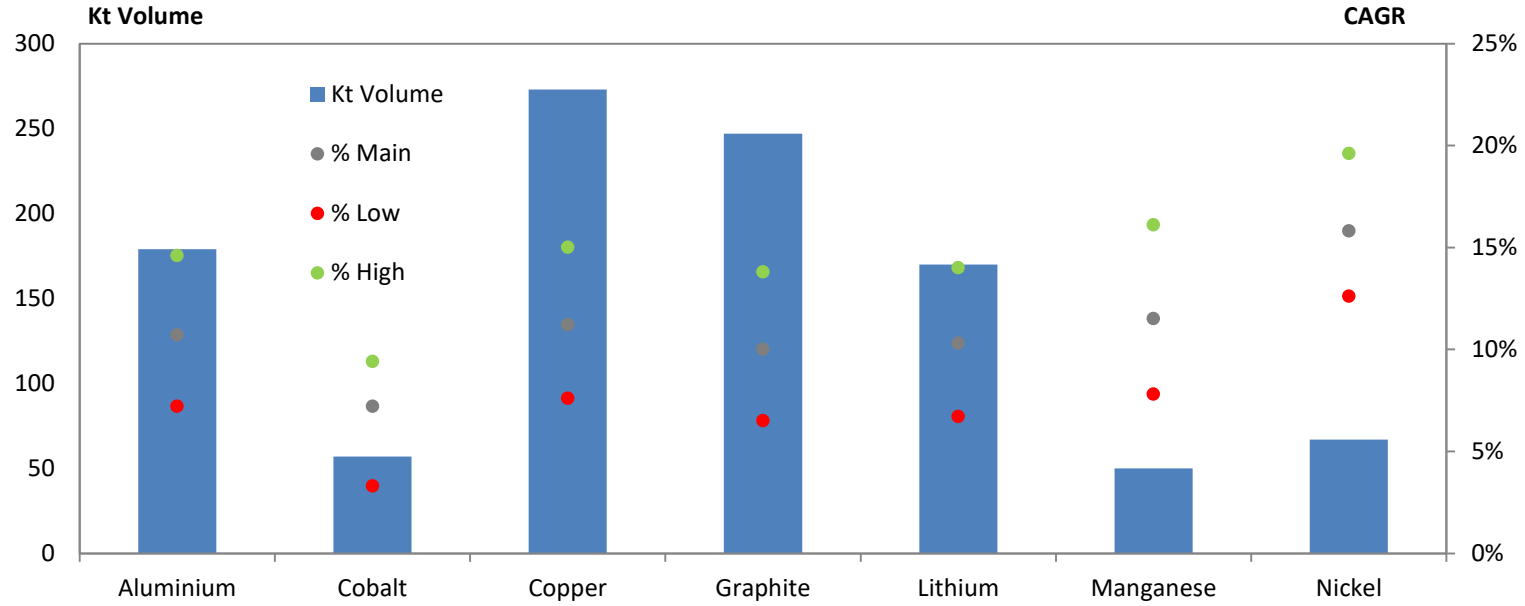




Source: Various

Battery raw materials: Nickel to outperform LIB market, cobalt worst performer on cathode formulation changes

Outlook for battery raw materials to 2025



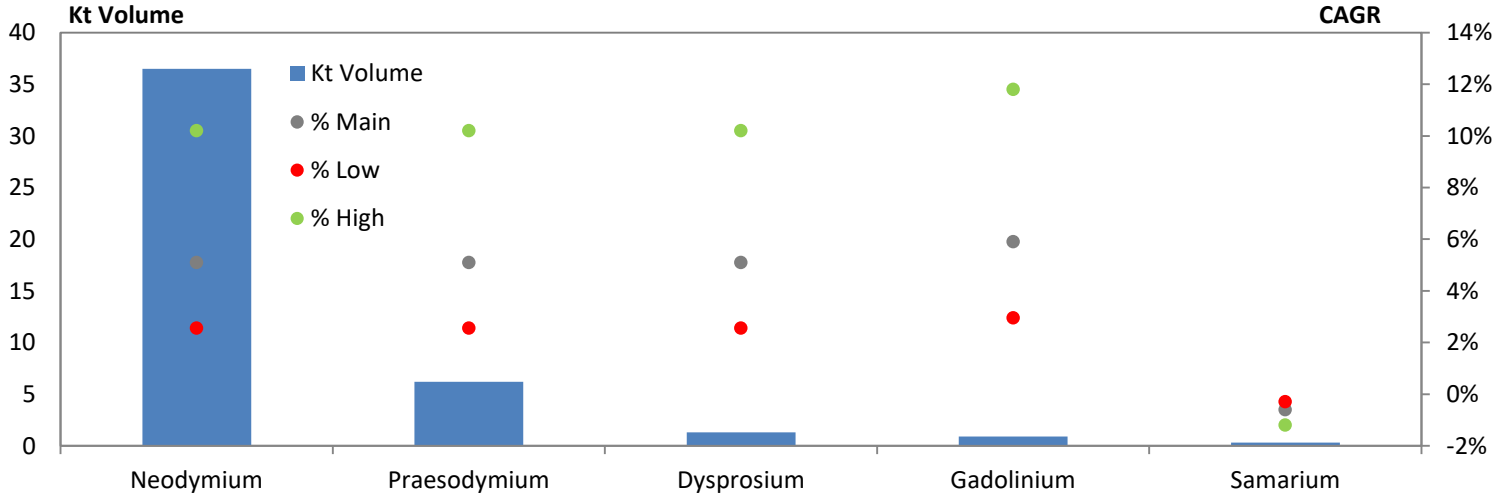
- **Cathode trend –** shift to high-nickel (NMC, NCA) containing materials (high energy density) in EVs, mix of LFP and NMC in ESS = benefit to nickel over cobalt. Lithium likely to see 1:1 growth with LIB market
- **Anode trend** - graphite to remain dominant, natural graphite preferred but synthetic competition increased when prices high; silicon gaining traction but >2020 mass commercialisation
- **Collector trend** – Copper and aluminium to track LIB growth ~1:1, opportunity for added value materials

Source: Roskill

Magnet raw materials: Demand could be stymied by supply issues, price ceiling before substitution (repeat of 2011/12)

- **Neodymium –** Staple constituent of NdFeB, currently large part of supply from "illegal" mining in China, demand could be limited by supply into 2020s
- **Praseodymium –** Mainly present due to use of NdPr alloy which is a cheaper alternative to separated Nd,
- **Dysprosium** – Additive to increase heat tolerance of NdFeB, gradually being removed since price spike of 2011/12
- **Gadolinium & samarium** – used in non-NdFeB magnets, niche applications, not inextricably linked to renewable energy or xEV market growth

Outlook for magnet REEs to 2025



Source: Roskill

Cobalt: LIB use shifting from staple to additive, will continue to grow but not at very high rates

	CRM Risk
Supply factors	
▪ Cobalt is abundant and deposits are spread across several regions	☒
▪ Reserves are sufficient to last for the long term	☒
▪ Mine production is spread across the world…	☒
▪ But is heavily concentrated in the DRC	☑
▪ And is heavily tied to certain nickel and copper operations	☑
▪ The supply pipeline looks healthy	☒
▪ Recycling of cobalt is considerable in some applications	☒
Geopolitical factors	
▪ Cobalt mine production is heavily concentrated in the DRC	☑
▪ Cobalt refined production is heavily concentrated in China	☑
▪ There are perceived geopolitical risks associated with trade with both	☑
Demand factors	
▪ Cobalt demand is expected to increase	☑
▪ Cobalt is used in many key applications such as batteries	☑
▪ But it is falling out of favour in batteries for xEV/ESS	☒
▪ It can often be substituted – but in many applications is the best material	☒

Source: Roskill

Lithium: LIB use accelerating with xEV/ESS, supply now struggling to keep pace

	CRM Risk
Supply factors	
▪ Lithium is abundant and deposits are spread across several regions	☒
▪ Reserves are sufficient to last for the long term	☒
▪ Mine production is heavily concentrated in Chile/Argentina & Australia	☑
▪ And increased role of refiners in China using Australian feedstock	☑
▪ The supply pipeline looks healthy	☒
▪ Recycling of lithium is poor (currently uneconomic from most products)	☑
Geopolitical factors	
▪ Lithium mine production is heavily concentrated in three countries	☑
▪ Lithium refined production is increasingly concentrated in China	☑
▪ There are perceived geopolitical risks associated with trade with both	☑
Demand factors	
▪ Lithium demand is expected to increase significantly from battery market	☑
▪ Price movement may reduce use in lower value applications	☑
▪ No substitute (yet) in LIBs, hard to substitute in some other applications	☒

Source: Roskill

Graphite: LIB use accelerating with xEV/ESS, supply concentrated in China

	CRM Risk
Supply factors	
▪ Graphite is abundant and deposits are spread across several regions	☒
▪ Reserves are sufficient to last for the long term	☒
▪ Mine production is heavily concentrated in China	☑
▪ And increased role of refiners in China producing battery-grade	☑
▪ The supply pipeline looks healthy	☒
▪ Recycling of graphite is poor	☑
Geopolitical factors	
▪ Graphite mine production is heavily concentrated in China	☑
▪ Graphite refined production is increasingly concentrated in China	☑
▪ There are perceived geopolitical risks associated with trade with both	☑
Demand factors	
▪ Graphite demand is expected to increase significantly from battery market	☑
▪ Price movement may reduce use in lower value applications (refractories)	☑
▪ No substitute (yet) in LIBs, hard to substitute in some other applications	☒

Source: Roskill

Neodymium: Use accelerating with xEV, supply could struggle to keep pace from 2020s

	CRM Risk
Supply factors	
▪ Neodymium is abundant and deposits are spread across several regions	☒
▪ Reserves are sufficient to last for the long term	☒
▪ Mine and refined production is heavily concentrated in China	☑
▪ Mine production is reliant on economics of basket of REE products	☑
▪ The supply pipeline looks healthy (albeit economics are key)	☒
▪ Recycling of rare earths is growing and increases with price	☒
Geopolitical factors	
▪ Neodymium mine production is heavily concentrated in China	☑
▪ Neodymium refined production is heavily concentrated in China	☑
▪ Neodymium/magnet recycling and demand is heavily conc. in China	☑
▪ There are perceived geopolitical risks associated with trade	☑
Demand factors	
▪ Neodymium demand to increase from magnet market (for xEV)	☑
▪ Price may reduce use in lower value magnet applications and eventually xEV	☑
▪ No substitute (yet) in permanent magnets	☒

Source: Roskill

Environment/Social: Extraction has social and environmental consequences, making these materials not so green!

Cobalt mining in the DRC

Graphite mining in China

Lithium extraction in Chile

REE mining in China

Source: Various

‘How to tackle potential supply shortage’

…invest in project development, improve recycling…

= still to be tackled for “green” CRMs

How to take advantage of “green” CRM demand

Cobalt

- What are the alternatives to the DRC/China?
  - Potential primary mines in ROW are higher cost than by-product = risk
  - By-product mines rely on nickel/copper economics = low exposure
- Only product with a terminal exchange listing = tradeable

Lithium

- Chinese converters reliant on imported concentrate = mine supply
- Current brine sources have capacity limitations = alternatives
- Incumbent producers have limited pipeline = M&A activity

Graphite

- What are the alternatives to China?
  - Potential new mines need route to battery market and low cost = risk

Neodymium

- What are the alternatives to China?
  - Potential new mines are reliant on basket of products = cost/price risk
  - Recycling of magnet/components = access to supply chain

Q&A

Roskill Research & Consulting

Consulting:

- Market assessments
- Feasibility studies
- Industry analyses
- Acquisition studies
- Strategic planning
- Competitive evaluation studies
- Commercial intelligence
- Due diligence

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Research coverage:

- Steel alloys:
  - Nickel, chrome & moly
  - Iron ore, silicon & manganese
  - Vanadium & niobium
- Minor metals:
  - Tin, tungsten & tantalum
  - Rhenium, gallium & indium
  - Antimony, cobalt & REEs
  - Lithium, magnesium & titanium
- Industrial Minerals, e.g.:
  - Bauxite, alumina & mag comps.
  - Feldspar, zircon & soda ash
  - Bentonite, barytes & frac sand
  - GCC/PCC, kaolin, talc & vermiculite
- Carbon & chemicals, e.g.:
  - Act. carbon, graphite & pet coke
  - Salt, iodine & boron

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