Energy Research Partnership

Cross-cutting Report

THE POTENTIAL IMPACT OF RESOURCE CONSTRAINTS ON UK ENERGY INNOVATION AND SYSTEM DEVELOPMENT TO 2050 - MINERALS: POLICY SUMMARY

The Energy Research Partnership

The Energy Research Partnership is a high-level forum bringing together key stakeholders and funders of energy research, development, demonstration and deployment in Government, industry and academia, plus other interested bodies, to identify and work together towards shared goals.

The Partnership has been designed to give strategic direction to UK energy innovation, seeking to influence the development of new technologies and enabling timely, focussed investments to be made. It does this by (i) influencing members in their respective individual roles and capacities and (ii) communicating views more widely to other stakeholders and decision makers as appropriate. ERP's remit covers the whole energy system, including supply (nuclear, fossil fuels, renewables), infrastructure, and the demand side (built environment, energy efficiency, transport).

ERP is co-chaired by Professor David Mackay, Chief Scientific Advisor at the Department of Energy and Climate Change and Dr Keith MacLean, Director of Policy and Research at Scottish and Southern Energy. A small in-house team provides independent and rigorous analysis to underpin ERP's work.

ERP is supported through members' contributions:

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Dr Keith MacLean	Policy and Research Director	Scottish and Southern Energy

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Rob Saunders	Head of Energy	Technology Strategy Board
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Nick Winser FREng	Executive Director, Transmission	National Grid

The Energy Research Partnership Cross-cutting Reports

The ERP Technology Reports provide an overarching insight into the Research, Development and Demonstration (RD&D) challenges for key low-carbon technologies. Using the expertise of the ERP membership and wider stakeholder engagement, each report identifies the innovation challenges that face a particular technology, the state-of-the-art in addressing these challenges and the organisational landscape (both funding and R,D&D) active in the area. The work identifies critical gaps in innovation activities that will prevent key low-carbon technologies from reaching their full potential and makes recommendations for investors and Government to address these gaps.

The following have been involved in the ERP Resource Use Strategies Review:

Lead Analyst Dr Mark Workman, Energy Research Partnership

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Thank you also for the contributions of Dr Julian Allwood (University of Cambridge) and his Wellmet 2050 and Foreseer Research Teams, Julie Hill (Green Alliance), Jaakko Kooroshy (Chatham House), Peter Willis (Oakdene Hollins), Jamie Speirs and Charles Dean (PhD Students at Imperial College, London) and David Humphreys (Independent Consultant and Minerals Economist).

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Box 1: The ERP and UKERC Mineral Resources Projects

The Energy Research Partnership's (ERP) Mineral Resources project was conducted in co-operation with the UK Energy Research Centre (UKERC) Technology and Policy Assessment (TPA) team. The TPA conducted a systematic review of the critical metals literature in a project entitled "*Materials availability for low carbon technologies.*" Given the similar nature of these two projects the authors co-operated by sharing emerging findings, bilateral meetings, and through ERP participation in the TPA Expert Group process.

The UKERC TPA take an evidence-based approach, including the systematic review of existing literature to address contentious topics in energy policy. This is complemented through engagement with stakeholders from industry, academia and the public sector. The resulting reports are designed to be independent, accessible and policy-relevant.

The approach taken by UKERC and ERP on minerals resources allows for a comprehensive review of issues both from the literature and key UK energy system stakeholders.

The TPA Materials availability for low carbon technologies report can be found at www.UKERC.ac.uk/TPA

Contents

1. Key Messages

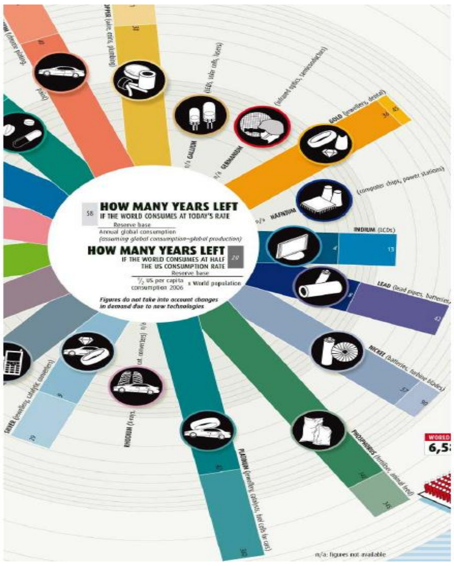
The key messages from the review are:

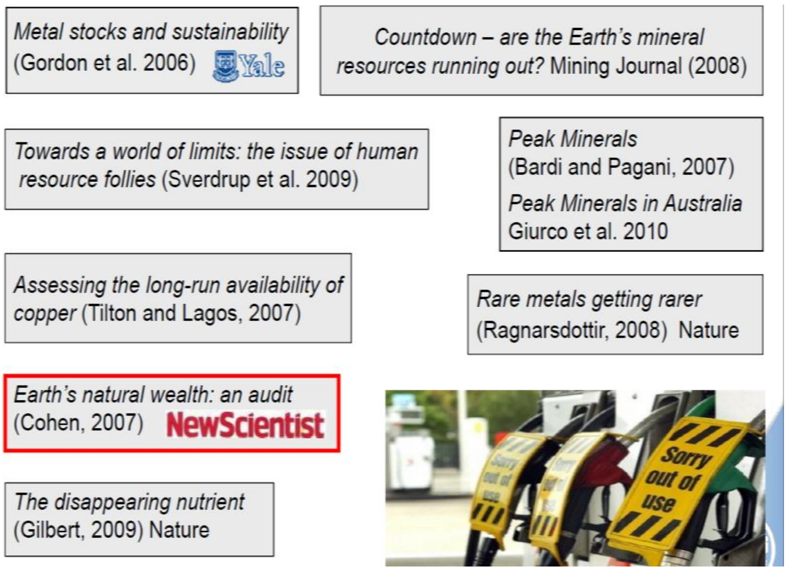
- ***The most potentially significant metal minerals constraint risk to UK energy innovation and system development to 2050 may be posed by the volatility in price and potential disruptions to the availability of `technology metal minerals' used in both conventional energy generation and low carbon technologies***. Supply uncertainty is the key concern. The availability of technology metal minerals at reasonable economic costs is essential to facilitate the rapid commercialisation of the low carbon energy system.
- ***Although there is no absolute shortage of any metal mineral resources, absolute availability is not a meaningful guide to prospective future production and availability, because of the impacts of economics and geopolitics***. The key constraints are related to the volatility of price and potential supply disruptions. The uncertain abilities of ecological sinks to assimilate anthropogenic generated waste from the exploitation and processing of metal minerals are likely to present further challenges.
- ***Resource risk assessments require a system based perspective, especially of supply and demand side issues in order to account for market dynamics and ensure the development of appropriate policy responses.*** There is a concern that some metal mineral assessment tools are likely to lead to inadequate and miss-directed policy responses.
- The impact of metal minerals non-availability on the UK economy has yet to be quantified, and is likely to be similar to other mineral consuming nations. ***However, the UK's response to the issue has tended to be non-interventionist.*** This is in contrast to proactive initiatives that other governments are taking, particularly in the securing of upstream supply and funding research into developing secondary sources. ***In the long run, the UK is therefore likely to be at a comparative disadvantage and should markets remain tight, the ability to develop a high value manufacturing sector will be jeopardized and the value creation opportunities of implementing mineral security measures will be missed e.g. material efficiency through better design, reuse and recycling technology development***.

2. Background

Over the next 40 years, analysis suggests that investment in energy innovation could reduce the cost of meeting the UK's low carbon energy goals by £600bn[1]. These savings would reduce the upward trend in energy costs across the economy making the UK more competitive. Furthermore, energy technology development could result in UK business opportunities totalling at least £18 Bn to 99 Bn to 2050[2]. However, recent surveys have identified that some UK executives, particularly those in the manufacturing sector, are concerned about the availability of resource inputs and the economic impact that it may have on UK competitiveness[3,4,5] - potentially jeopardising energy goals and green growth opportunities.

These concerns are reflected in the recent academic and grey literature which have expressed concern regarding the absolute depletion of some minerals - Figures S1 and S2. This in turn has led to a resurgence in the production of criticality assessments. However, the materials identified as being critical in the assessments have been inconsistent - Figure S3.





Material/report	EU	TSB	Defra	SEPA	STC	BGS	US
Aggregates			X	X			
Antimony	X	X			X	X	
Beryllium	X				X		
Bismuth						X	
Bromine						X	
Chromium					X		
Cobalt	X			X	X		
Copper				X			
Fish			X	X			
Fluorspar	X						
Gallium	X				X		
Germanium	X				X		
Gold		X			X		
Graphite	X						
Hafnium					X		
Indium	X		X	X	X		X
Lithium			X	X	X		X
Lead				X			
Magnesium	X				X		
Mercury		X				X	

Figure S1 to S3 (clockwise from above): S1: A modern assessment of minerals availability based on Reserves/Production Ratios - a physical fixed stock measure[6]; S2: A collection of quotes / papers citing concerns over resources[7]); and S3: Table 1 from the Green Alliance Report 2011 `*Re-inventing the Wheel*'[8] highlighting the differing materials that are identified as being at critical risk from different studies.

The Energy Research Partnership (ERP) has undertaken a review of resources in order to understand these issues and assess whether resource availability will represent a significant risk for UK energy innovation and system development to 2050. This report refers to the component of the review dedicated to metal minerals (i.e. excluding fuel minerals e.g. oil and coal and non-metals e.g. aggregates) used in high tech and energy system applications. Resources are assessed according to the following categories: minerals, water and land issues. These categories are covered in separate reports and a nexus report, ties the different strands of work together in a single overarching document. The work has been undertaken in collaboration with the UK Energy Research Centres' Technology Policy Assessment on Minerals Availability and refers heavily to the systematically gathered evidence from that work - see Box 1 on page 3.

3. Summary of Findings

3.1 The Resource Constraints Agenda - Drivers of the Present Wave of Concern

Resources concerns are not a new phenomenon. There is a rich literature expressing concern over resource availability dating back three millennia[9]. Recent concerns have been stoked by the following drivers:

- The rapid growth of the middle class which is anticipated to grow by 3 Bn to 4.8 Bn in 2030 and the speed and scale with which the emerging economies are growing[10];
- This growth is set against a world that is increasingly interdependent[11];
- The increasing fragmentation of land-ownership making access to resources more complex[12] despite the parallel growth in influence of a limited number of trans-national mining corporations in this sector. This situation has been exacerbated by the rise of resource nationalism;
- The unprecedented impact that economic development has had on global ecosystems[13,14]; and
- Concerns over inequitable access to resources[15,16].

3.2 The Role of Metal Minerals in Energy System Technologies

Energy innovation and system development exposure to metal minerals has increased as a result of the ***proliferation in the use of increasingly exotic elements***[17] and the ***increased mineral intensity of new energy technologies; many are essential in the development of the low carbon energy system to 2050***[18]. This concern has been exacerbated by the development of energy systems in rapidly emerging economies and the need to replace a significant proportion of the aging energy generation infrastructure in OECD nations. For example, by 2020 the energy systems of China, the US, India, Japan, Germany and the UK are anticipated to install 1,350 GW of power generation capacity of which 728 GW will be low carbon technologies. ***Consideration of primary supply of minerals is important in the near term, not only because of the expansion of energy systems but also because the long lifetime of assets means that minerals are `locked-in', unavailable for recycling for many years. Recovery and recycling, however, may become critical and should be taken into account in current decisions.***

With the uncertainties in the way that energy system technologies will evolve and the configuration of the low carbon energy system in the future the exact nature of the low carbon transition impact on minerals demand can only be considered to be illustrative[19]. Nonetheless, ***the extent of the potential impact is such that further work is required to understand the feasibility and impact of these different options from a resource inputs point of view*** (see for example, ICMM, 2012[20]).

3.3 Metal Mineral Availability Assessment Tools for Decision Support

A key manifestation of the concerns over minerals availability has been the proliferation of criticality assessments[21]. The criticality literature has evolved from mineral consuming countries and/or actors based on their concerns of reliable sources of supply of key elements. Like concerns over resources there have been previous tranches of criticality literature with the latest set being the third. The minerals which are currently deemed under threat are typically within a range of specialised, low volume metals used in the production of technologically-advanced consumer electronics, low carbon technology products and defence applications[22]. The pervasive nature of the products within which the minerals now designated as critical are used makes assessments of the impacts harder and has increasingly blurred the distinction between different applications[23]. ***Therefore the most recent criticality assessments have struggled to assess the relative importance of the varied end uses of the minerals and their economic impacts***.

However, the outputs of the criticality literature, including those directed at energy system development, has displayed considerable inconsistency in the nominated minerals identified as being `critical'; they are also considered inappropriate to inform policy. The reasons for this may be attributed to the following issues[24,25,26]:

- Methodologically they are inconsistent using different criteria, methods of computation / aggregation, weighting and limited by the availability of up to date information - for detail see the UKERC Minerals Final Synthesis Report Part 1;
- The criticality literature gives a static and `snap-shot' status of minerals supply and demand when the factors at play are dynamic, for example, see Houari et al., 2013[27];
- Assessments of supply risk and demand are difficult due to uncertainties and the limited availability of data at the appropriate frequency - for detail see the UKERC Minerals Final Synthesis Report Parts 2 & 3;
- The criticality literature focuses exclusively on risks related to the mining and export of raw materials, but disregard the wider production chain (e.g. refining, transport, and trade in semi-products); and
- They tend to overstate the economic impact of a possible supply disruption of 'critical' minerals and do not explicitly declare the often highly subjective risk perspective that the reviewers have undertaken which is important in order to facilitate the appropriate policy design.

The criticality literature appears to be stimulating sub-optimal policy design, for example, in the EU Raw Materials Initiative which emphasises three aims: (1) Fair and sustainable supplies from global markets; (2) Fostering sustainable supply from within the EU; and (3) Boosting resource efficiency and promoting recycling. It has been suggested that a more systems based approach would also incorporate (4) information gathering and analysis on raw materials; (5) improving supply chain management; (6) Promotion of exploration and production (both inside and outside the EU); and (7) dialogue and collaboration with other mineral importing countries and exporters[28].

Given the difficulty of forecasting future political and economic events and the variations in national consumption a `Delphi' (discussions with experts) or ***more deliberative Multi- Criteria Mapping method*** based on a simplified model[29] ***could probably provide more insight than criticality scores or other snap-shot assessments***. This way, assuming the attendance of the appropriate experts, a more thorough understanding of all the risks surrounding the availability of a particular resource will be realised and may be more useful to stakeholders than a simple prioritisation or classification of `critical minerals'.

Ultimately, the ability to forecast minerals depletion is subject to considerable uncertainty and all methods ranging from fixed stock to economic have flaws[30]. Indeed, though some components of minerals availability are knowable (e.g. the nature and incidence of the available mineral deposits) many of the variables are not only unknown but are also unknowable (e.g. the future demand, extent to which demand will be satisfied by recycling and other secondary production and cost reducing technological change for minerals extraction) ***therefore information about minerals availability and depletion `is a function of information that is available at a particular time and that information changes over time'***[31]. For example, see the case study reports in the UKERC Minerals work stream.

3.4 Minerals Abundance and the Environmental Impact of Mining

Geochemical analysis of the earth's crust, atmosphere and sea water indicates that there are plentiful supplies of minerals on the earth - though their concentration is highly variable[32,33,34]. Furthermore, unlike fuel minerals, metal minerals are not destroyed once they are *`consumed by society'* and so are potentially re-usable. So though primary ores are exhaustible and are decreasing there are increasing stocks in the techno-sphere[35].

However, the role of economics (technology development and physical concentration of metal ores), geopolitics (physical access to the minerals and proximity to markets) and the environmental implications of extraction and recovery means that absolute availability is not a meaningful guide to prospective future production and availability.

Based on the literature reviewed it is therefore possible to state that ***there is no absolute shortage of any metal mineral resources.*** The key constraints are related to the volatility of price and potential supply disruptions.

The mining sector has a substantial ecological footprint impacting on water resources, air quality, land - soil quality and habitat loss - and greenhouse gas footprint. Furthermore, with the decreasing quality of ore grades the energy and water needs are increasing[36] as is the waste[37] that is produced and area impacted to extract a unit of ore. Despite this, technology has evolved allowing lower grade ores to be extracted at economically viable prices as has been evidenced in the increased prevalence of opencast mining. The refining of ores also generates a globally significant carbon footprint and approximately >4 % of global greenhouse gas emissions arising from iron ore production and refining[38]. ***It is likely therefore, that a significant increase in demand for minerals will have a material impact on the sectors global emissions and the ability to attain the 2°C CO_2 budget[39,40] as well as its local environmental footprint***.

Furthermore, with a substantial proportion of ecosystems already under significant strain[41] and with the increased prevalence of opencast mining - a key concern is ***the uncertain abilities of ecological sinks to safely assimilate anthropogenic generated waste from the exploitation and processing of metal minerals. As such sink resources are therefore likely to present the most significant scarcity***.

3.5 The Market Behaviour of Technology Metal Minerals

There are a family of metals called `Technology Metal Minerals' - also referred to as minor, special and precious metals - often utilised in high tech and low carbon applications. A significant subset of technology metals are (1) metals that are available as primary products but tend to be more economical to produce as by-products; (2) metals that are found coupled in ore deposits; (3) metals for which there are only small markets with only a handful of suppliers where producers wield disproportionate power; or (4) a combination of 2 or more of these traits. These metals are subject ***to weak market signal*** and ***as a result markets operate imperfectly for many of these metal minerals markets.*** The lack of information along their life cycle from production, refining, trade to end use compounds the ability for markets to function efficiently.

The traits of these metal minerals are:

- ***By-product metals*** which are produced as a minor product in the production process of a main element such as copper or zinc. The concentrations of main or carrier element is available at percentage ranges, while the by-products are available at ppm range and produced at substantially lower volumes. Sometimes they can be extracted economically enough to add to profitability but in other cases they are considered an impurity therefore increasing the production costs of the main element. ***These factors mean: that there are no meaningful estimates of reserves for these minerals so calculations of reserve life cannot be made; that they are prone to prolonged supply constraints since their availability cannot be easily adjusted to increases in demand; and as a result that they are subject to limited correlation between prices and production volume.***
- ***Coupled minerals*** are groups of minerals, such as the 17 Rare Earth Elements (REE) and 6 Platinum Group Elements (PGE) which typically occur together due to their geo-chemical properties being very similar. They therefore have to be mined and processed together i.e. a single REE (e.g. Dysprosium) or PGE (e.g. Rhodium) cannot be mined individually. ***This makes them subject to balancing problems as each element has to be extracted in different quantities depending on the respective quantities in ore bodies which often do not reflect market requirements.***
- ***Minerals whose production is subject to monopoly and oligopoly power (national or corporate).*** For example, REE (which are also coupled elements) are predominantly produced in China (where presently 97% of global production is based). ***This makes them subject to producer power which potentially results in elements not being available at the quantities that matches market needs***.

The most potentially significant metal minerals constraint risk to UK energy innovation and system development to 2050 may be posed by the volatility in price and potential disruptions to the availability of these `technology metal minerals' used in both conventional energy generation and low carbon technologies. Supply uncertainty is the key concern. The availability of technology metal minerals at reasonable economic costs is key to facilitate the rapid commercialisation of the low carbon energy system. There is also an element of lock in to some of these technology minerals due to the inability to substitute in the medium to short term. There are, however, policy responses available to reduce the risk of supply constraints. In order to understand these, the mining sector and metals minerals markets need to be better understood; these are explained in sections 3.6 and 3.7, below.

3.6 The Mining Sector

The mining sector is highly heterogeneous ranging from vertically integrated mining giants to small, single mine / refinery or exploratory companies called Juniors - *see figure S4*. The different groups use different business strategies to manage risk and create growth opportunities.

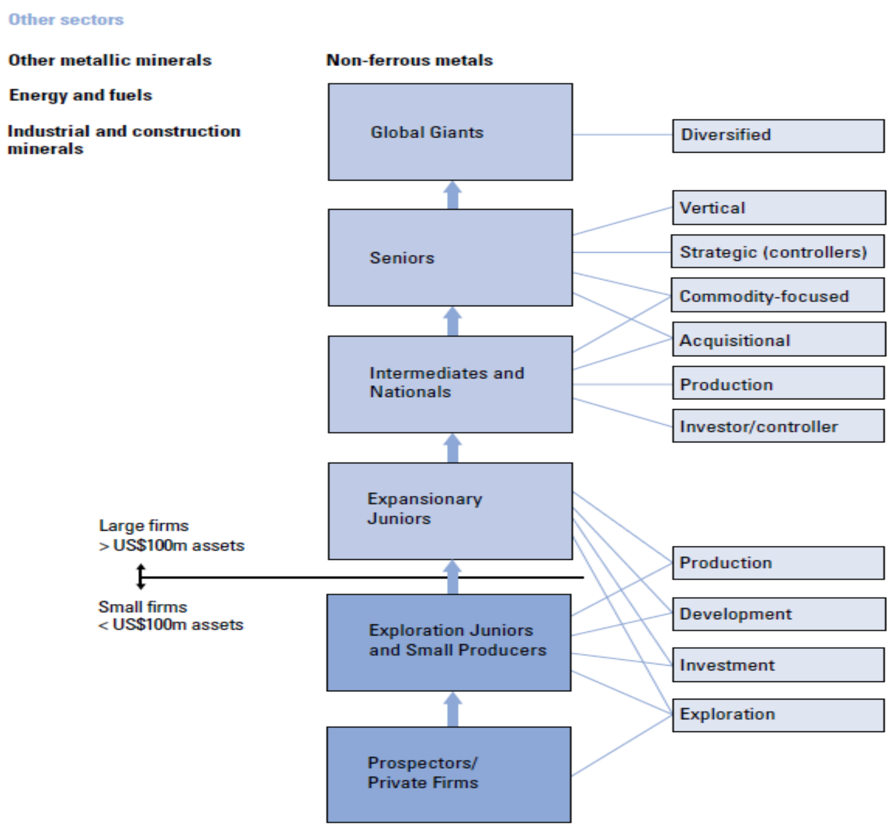


Figure S4: Global Corporate Mining Sector firm size and operational focus.

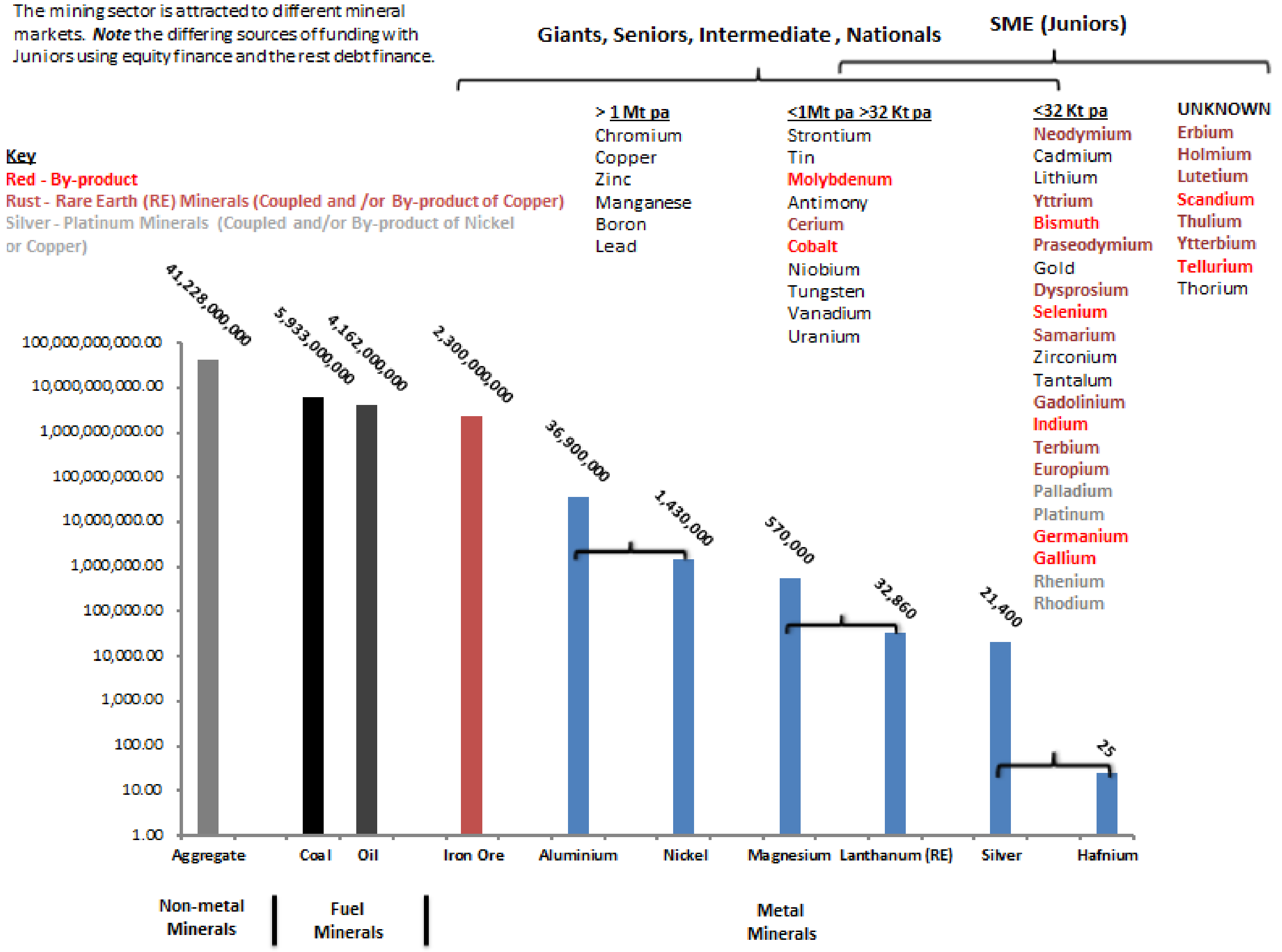
Junior companies find new ore bodies and sell them on to the larger companies. Intermediates offer growth potential through merger among themselves or by being taken over by the largest corporations. Miners feed product to smelters and refiners, who in turn provide metals or mineral products to fabricators, and so on. Thus, in this sense, the industry is highly interdependent, both along the product supply chain and across different mineral groups[42]

3.7 Metal Minerals Markets and Mining Sector Responsiveness

In contrast to the few fuel minerals, non-fuel minerals comprise a relatively large heterogeneous group; therefore ***few significant general observations can be made about them***. However, metal minerals are less fungible and bottlenecks more likely.

The volumes traded on metal minerals markets are highly varied and substantially smaller than other minerals sectors. For example, metal minerals extracted in 2009 totalled 2.41 Gt compared to the global aggregates market at 41.2 Gt, coal at 5.9 Gt and oil 4.2 Gt. Metal minerals market size ranges from Iron ore at 2.07 Gt (95% of 2009 metal minerals markets) to the 32 metals which are (or in some cases estimated) to be produced at sums of 32 kt or less making up 112 kt (or 0.005% of 2009 metal minerals markets) in total per annum. Indeed the volumes produced for a number of minor metals are not available. Many of the metal minerals essential to the development of high tech and energy system technologies are in these smaller markets - see figure S5, below. For example, hafnium - critical for low carbon, CCGT and nuclear technologies - had a global production of 25t in 2009.

Figure S5: The scale of different minerals markets (note the Log10 scale on the y axis) showing the different mining sectors that are attracted to different markets and the tendency for technology metal minerals (including by-product and coupled minerals) to be in the smaller markets[43,44,45,46].



In terms of metal mineral market dynamics the following recent trends are salient with regards contemporary concerns of minerals resource availability from metal mineral consuming nations:

- The demand side is characterised increasingly by non-OECD nations which now consume substantial proportions of the world's production, especially China, which in 2009, accounted for 47.7% of global Iron Ore, 45.4% of global Steel, 44.6% of global Lead, 41.3% of global Zinc, 40.6% of global Aluminium, 38.9% of global Copper and 36.3% of global Nickel - albeit much of this was subsequently exported in products.
- On the supply side there is shift of mining activity from OECD nations to emerging economies and increasing company concentration, for example:
    - China is now the world's largest mining country with (Brazil (No 6), Russia (No 5), India (No 4), South Africa (No 6) among the top 10 mine producers. The only developed economies among the top 10 countries are Australia (No 2), USA (No 3) and Canada (No 10). The role of European and US mining as a proportion of mined metals by value has been in decline since 1850 which has reduced minerals security for these nations - see figure S6, below; and

- Company concentration can be found in the supply chain for Iron ore where 32% of production is concentrated in 3 of the world's largest mining organisations (Vale 14.1%, BHP Billiton 8.1% and Rio Tinto 9.8%).

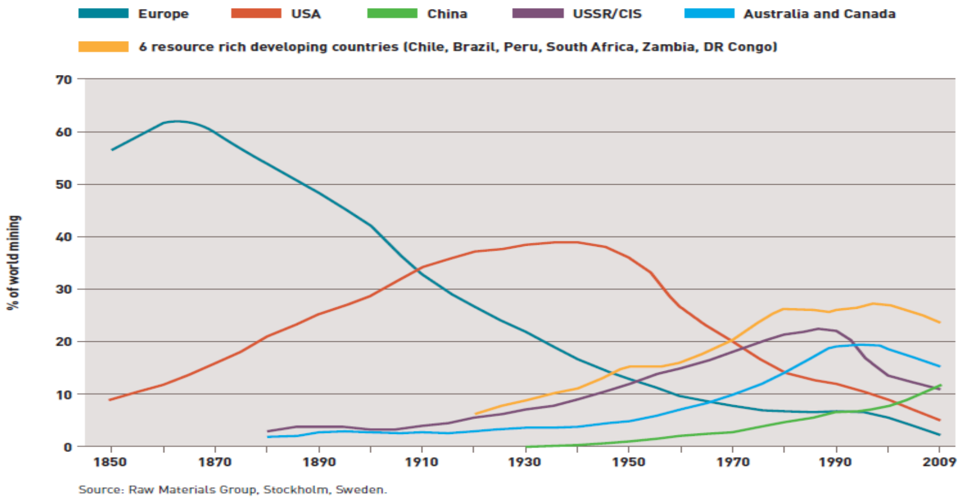


Figure S6: Location of mining by region since 1850 to present. Measure is as a function of total value at the mine stage of all metals produced by all countries[47]. It is worth noting that the minerals sector has also increased 31 fold from 68 M tonnes in 1900[48] to 2.41 Billion tonnes in 2009[49].

- ***The mining sector is renowned for being extremely conservative in its responsiveness to price spikes due to the capital intensive nature of the industry.*** Therefore, investment response to increased demand can take 2 years to be realised - see figure S7. This investment leads to exploration activity being ramped up, with new mine developments typically requiring careful advanced assessment including environmental and social baseline studies, extensive ground preparation, the construction of plant, the acquisition of specialised equipment and the creation of facilities for the disposal of mine waste and not uncommonly they will also require the building of railways, ports and power stations. Therefore, there are even longer lags between the price signal and the time that the investments have an impact on supply, for example, figure S8 indicates that there is an 8 year lag for copper. For a detailed breakdown of the macro-economics of the sector in the recent commodities boom (2003-2008) - see Humphreys (2010)[50]. ***These traits are, however, most typical of the Giants, Seniors, Intermediates and Nationals - figure S4 and larger minerals markets - figures S4 and S5.***

Figure S7: Investment in non-ferrous mining and metals relative to price[51].

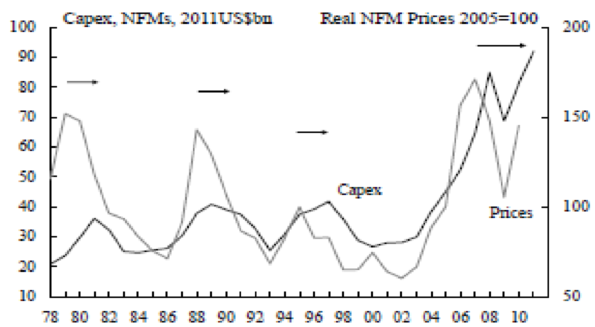


Figure S8: Copper prices and mine production[52].

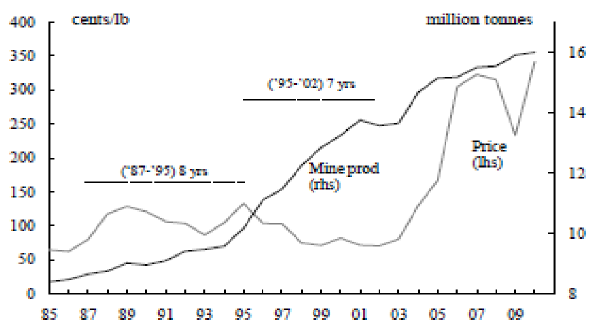


Figure S7, shows the time lag between investment (left axis) and non-ferrous market prices (right axis) of 2-3 years. Figure S8, shows copper production relative to prices showing a gap of 7-8 years between peaks.

- ***The most market responsive part of the sector are the Juniors which are funded by a different set of investors and according to a different set of economic drivers and set of investors from those of the mining giants - figure S9***. They also tend to focus on smaller minerals markets (by value and volume) - figure S5. They are likely to be responsive to the notion of a mineral's criticality and the public profile of a mineral. This is because equity capital for a project becomes easier to promote if the product a junior is expected to recover is viewed as having an exciting growth prospect; especially when this is reflected in strongly rising prices, as funding is more readily available at such times. ***This is the sector that should be the focus for targeting policy with regards to stimulating small minerals markets and technology metal minerals.***

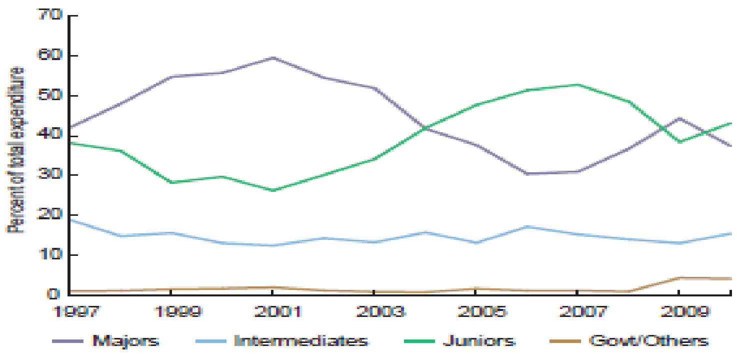


Figure S9: **Worldwide exploration by company type (% shares)**[53]

Note. These figures probably underestimate total exploration as MEG figures do not include exploration by state companies and other state organisations.

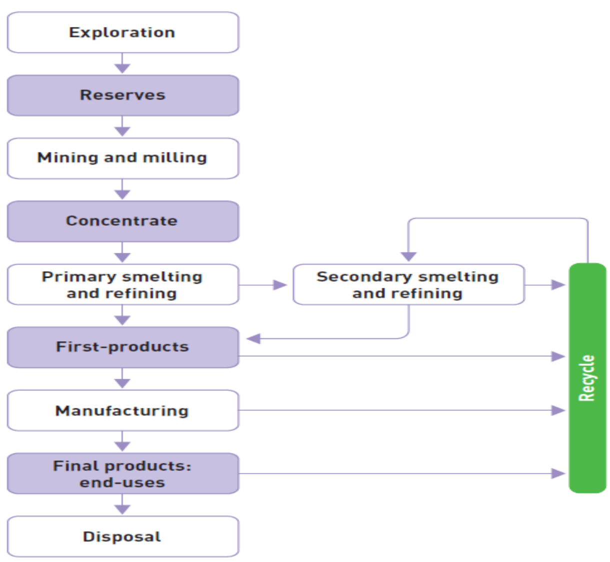
3.8 Economic Countermeasures to address Technology Metal Minerals Constraints

There are a number of economic countermeasures that may address minerals availability along metal minerals life cycle - figure S10. They have differing response times - these are summarised in figure S11 related to energy generation technologies.

Figure S10: Countermeasures for market balancing related to minerals product life cycles.

Enabling

- Improved awareness, data collection and dissemination to improve the transparency of the markets.
- Trade and international co-operation.



Supply Side

- Finding new sources of primary supply (e.g. more exploration and investment);
- Increasing secondary sources of supply (e.g. increasing recycling, exploitation of gauge piles or stockpiling[54]);

Demand Side

- Resource efficiency (in the final product, e.g. using less of an expensive component);
- More efficient use of the end-product (e.g. demand reduction);
- Substitution of the material by another material inside the same final product (demand destruction);
- Substitution of the end-product (demand destruction);

A key countermeasure is the implementation of these strategies by better design and innovation.

Figure S11: Economic countermeasures that may be implemented to address technology metal minerals supply constraints and their timeframes of operation. *It is noteworthy that though government can set the policy framework there is a role for business to take action and work with government to address the challenges.*

Economic Countermeasures for addressing Technology Metal Minerals Constraints for Energy System Technologies	Short-Term (0 - 5 yrs)	Medium Term (6 - 19 yrs)	Long Term (20+ yrs)
Enabling			
Awareness - Integration of resource issues in energy scenarios and Materials Flow Analysis			
Data Collection and Dissemination by Producers, Refiners and Manufacturers (e.g. Bill of Materials)			
Market Transparency - Registering on exchanges, Trade Statistics and Future Options			
Co-operation through international partnerships and knowledge exchange [e.g. R30]			
Ensure mechanisms to faciliate free trade and prevention of trade restrictions by minerals producers			
Better Design and Innovation for minerals efficiency			
Supply Side - Increasing Primary Sources of Supply			
Access to Risk Capital for Junior Miners			
Risk Reduction Policies for Junior Miners operating in geopolitically challenging Locations			
Exploration and Mapping Sources of Technology Metal Minerals			
Facilitating investment environment for mining in Non-OECD nations			
Incentives to improve R&D to enhance extraction efficiencies and reduce environmental impacts			
Encouragement of skills base in geology and geoscience			
Supply Side - Increasing Refining Capacity			
Information on opportunities for producton - ores with high concentration & refining scale up			
Incentivisation of by-product and coupled production by refiners			
Encourage R&D investment to improve the efficiency of by-product and coupled refining			
Supply Side - Increase Secondary Sources of Supply through Recycling[1]			
Assess recycling capacity for different technology metal minerals			
Incentivise R&D for the improvement of recycling technologies			
Incentivise Reuse and Remanufacture			
Recycling potential for different product streams (significant range depending on length of 'in-use' phase)			
Improve recycling system - collection, sorting, link agents, design and regulation alignment			
Demand Side - Materials Efficiency[2]			
Incentivisation of Takeback Options[3], Extended Producer Responsibility, Life Cycle Ownership & RRM[4]			
Demand Side - Substitution of Material			
Map R&D work that is taking place in materials substitution and information exchange			
Align actors in metal and technology value chains to target substitution efforts - Benchmark best practice			
Demand Side - Technology Substitution			
Awareness of technology substitution trends and impact on market balance			

1. The contribution of secondary supply from the energy sector will be limited due to rapid expansion of the sector and the life span of technologies which is at least 20 years. However, the opportunity from consumer goods such as mobile phones and computers may be more rapid (2-5 years)
2. The application of materials efficiency thinking to technology minerals is likely to be limited due to the quantitaties used in devices already generally being very small.
3. Take Back Options returns the product back to the manufacturer for re-use of the materials
4. RRM - Reuse and Remanufacture is the re-engineering of technology components for re-use either in new or the same technologies.

Key
: Research / Development.
: Implementable / Realisable.
: Range of timeframe from Research to Implementation.

3.9 Different National Responses to Technology Metal Minerals Constraints

The implementation of different minerals and metals policy options, outlined in figures S10 and S11, by different governments to ensure security of supply have been mapped and the degree of activity presented in figure S12.

Figure S12: Assessment of the different minerals policy activity being implemented by different governments to ensure security of supply[55,56,57].

	Enabling		Supply Side		Demand Side				
Country	Data / Market Transparency	Trade and Co-operation	Primary Supply	Secondary Supply	Resource Efficiency	End Product Efficiency	Material Substitution	Product Substitution	Technology Metal Minerals - Producer/Consumer
US	[green]	[green]	[green]	[green]	[amber]	[amber]	[amber]	[red]	**Producer** and Consumer
China	[green]	[green]	[green] 1.	[green]	[red]	[green]	[red]	[red]	**Producer** and Consumer
Japan	[green]	[green]	[green]	[green]	[amber]	[amber]	[amber]	[amber]	Consumer
EU	[green]	[green]	[green]	[green]	[amber]	[amber]	[amber]	[amber]	Predominantly Consumer
Germany	[green]	[green]	[green]	[green]	[amber]	[amber]	[amber]	[amber]	Predominantly Consumer
Australia	[red]	[green]	[green]	[red]	[red]	[red]	[red]	[red]	**Producer**
Canada	[red]	[red]	[green]	[green]	[green]	[green]	[red]	[red]	**Producer**
South Korea	[green]	[green]	[green]	[green]	[amber]	[amber]	[amber]	[amber]	Consumer
United Kingdom	[green]	[green]	[amber]	[amber]	[amber]	[red]	[red]	[red]	Predominantly Consumer

Key
- [green] Policy and Research Activity
- [amber] Research Activity
- [red] Little or Some Activity

Note
1. China has imposed tariffs for primary supply of some minerals notably for rare earth minerals.

Two clear trends are evident in figure S12:

- In the short-term, supply side policies are being implemented by all countries and demand side measures are being heavily researched; and
- There is also a split between mineral consuming and producer nations with producer nations (China, US, Australia and Canada) focusing on enhancing primary production and those in minerals consuming nations seeking to establish demand side reduction measures with some enhancement of primary production via indirect mechanisms and the encouragement of domestic production.

With this in mind it is worth highlighting that: though the impact of metal minerals non-availability on the UK economy has yet to be quantified, and is likely to be similar to other mineral consuming nations, ***however, the UK's response to the issue has tended to be non-interventionist.*** This is in contrast to proactive initiatives that other governments are taking, particularly on the securing of upstream supply and funding research into developing secondary sources. ***In the long run, the UK is therefore likely to be at a comparative disadvantage should markets remain tight, the ability to develop a high value manufacturing sector will be jeopardized and the value creation opportunities of implementing mineral security measures will be missed e.g. material efficiency through better design, reuse and recycling technology development***.

4. Recommendations

With these issues in mind, the ERP makes the following recommendations to ensure the UK has a globally competitive energy innovation sector:

- ***The location of responsibility for the monitoring of metals mineral non-availability risk should be better defined in government.*** Policy makers need to develop capacity to be aware of the characteristics of the individual mineral products under threat and understand better where and how they are produced, especially those which come as by-products of other minerals, or flow from the processing of imported ores.

- ***Resources risk assessments require a more holistic perspective of supply and demand side issues in order to account for market dynamics and ensure the development of appropriate policy responses.*** Surveillance systems should be established via the Foreign and Commonwealth Office UK Trade and Industry and Science and Innovation Network to identify international issues that might impact resources key to the UK and such issues should be fed directly into the UK National Security Council.

- ***Market transparency, awareness and the needs of upstream supply actors should be a priority to stimulate stronger market signals for technology metal minerals***. Transparency measures include:
  - the development of awareness of minerals use in energy technologies (e.g. via bill of resource inputs labelling) and impacts of minerals policies enacted by supplier nations;
  - Improved datasets through the incentivisation of the regular publication of production, trade statistics (at the appropriate level of disaggregation), or where the private sector lacks sufficient incentive to develop information on these minerals the funding of national geological bodies to conduct the research and produce data should be considered. In the UK, increased funding for the Resources Dashboard should be made so that the platform can be placed on line as soon as possible.
  - An increase in government focus to develop information and co-ordinate extension services to Small and Medium Enterprises who are likely to be most exposed to metal minerals non-availability and are key to UK energy innovation.
  - Promote more open pricing mechanisms where possible. When there is sufficient liquidity these metal minerals should be brought to exchanges. Until that level of liquidity is attained it is to be expected to that market balancing mechanisms may not be responsive as actors would like;
  - Primary supply initiatives include increasing the availability of risk capital for Junior miners for their exploration operations in unstable regions, where possible providing political support (ensuring environmental and social safe guards are in place) and encouraging investment and R&D in refining capacity to improve deployment and efficiency for by-product refining technologies, respectively.

- ***Investment into demand side research to address the root cause of minerals insecurity.*** These and the other countermeasures for addressing resource constraints should be incorporated within the evolving BIS Industrial strategies. Within this work the following should be considered:
  - Understand where value capture in high technology manufacturing Global Value Chains takes place, particularly those associated with conventional and low carbon energy generation technology development. This can build on the work undertaken in the Technology Innovation Needs Assessments undertaken by the Low Carbon Innovation Co-ordination Group such as the Low Carbon Innovation Strategy;
  - Scenarios need to be developed to better understand the second and third order impacts of supply constraints of technology metal minerals on UK energy innovation and system development as well as the wider economy - the ERP is of the understanding that some work in this area is underway for the wider economy;
  - This should include the removal of barriers to facilitate favourable economics for recycling as well as incentives for innovation in recycling technologies. Materials efficiency and substitution research initiatives should also be improved and co-ordinated with the UK manufacturing and design sector; and
  - Research of the impacts of the interaction of these policies on UK metal minerals supply chain needs to be undertaken *e.g.* there is the possibility that increased substitution and recycling may cancel each other out and the potential for bottle necks in secondary supply chains needs to be understood.

Specific recommendations for business include:

- Develop access to information platforms which will allow the development of capacity to be aware of technology metal minerals which are subject to supply constraints and innovation that is being undertaken in the relevant sectors of the economy which either will utilise increasing amounts of technology minerals or substitute them out;
- Develop a better understanding of supply chains and the exposure of these supply chains to disruption as a function of causes of metal minerals constraints;
- Have contingency measures established to address issues as they arise for example through vertical integration, stockpiling, minerals efficiency, the development of substitutes *etc.;* and
- Informing government of their concerns and working with government to address challenges.

End Notes

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