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The future impact of materials security on the UK manufacturing industry

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The future impact of materials security on the UK manufacturing industry

By

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Contents

Glossary

CHP	combined heat and power
CRM	critical raw material
EPOW	European Pathway to Zero Waste initiative
GVA	gross value added
HSLA	high-strength-low-alloy (steel)
IT	information technology
Li-ion	lithium ion (battery)
MW	Megawatt
NACE	nomenclature générale des Activités économiques dans les
Communautés	européennes (EU business activity codes)
NdFeB	neodymium iron boron (magnet)
NiNM	nickel metal hydride (battery)
PGM	platinum group metal
REE	rare earth element

Executive summary

Introduction

European manufacturing industry depends heavily on imported raw materials, with the EU-25 (pre-2006) importing around 21% by weight of its needs. This makes Europe the world region that outsources the largest part of resource extraction required to produce goods for final demand. In the UK, manufacturing's share of the economy is currently around 10%, and it faces challenges and competition from abroad. Globalisation of manufacturing has resulted in an increasing number of emerging economies competing for a limited pool of resources. Consequently, UK industry faces a growing problem of securing supply chains linked to particular materials.

In order to ensure a future of greater materials security, the UK Government needs to know the manufacturing industries that will be most affected and the materials supply chains of greatest risk. In addressing these issues, this review of existing data has two principal aims. The first is to determine the issues faced by the UK manufacturing industry in the future as a result of possible raw material limitations of supply; the second is to review and assess possible mitigation strategies. Both of these aims are examined for the short term (until 2020) and, where possible, the long term (until 2050). The report concludes with suggestions for action by Government and industry.

Materials in the scope of this work include metals and minerals, oil and gas when transformed into key intermediates, rubber and wood. Food production and processing is not in scope.

Manufacturing overview

Key industries have been determined using both UK manufacturing data and information obtained from existing reports. Using data from the Annual Business Inquiry for 2011, the value (as gross value added, GVA) of UK manufacturing sectors can be ascertained. These data provide a starting point for determining those industries most important to the UK economy but must be used in conjunction with more detailed and specific information.

However, current economic importance is not the only factor for inclusion. For example, industries that are small now may grow over the next 40 years into important elements of the UK economy. Furthermore, industries as a whole may not be affected by critical materials dependency but there may be adverse consequences for important sub-sectors within an industry.

In total, eighteen materials have been assessed for criticality across fourteen key applications.

Review of selected raw materials criticality studies

Critical materials are typically referred to as those for which there is an actual or perceived lack of availability. Criticality is not purely a problem of geophysical scarcity but also involve other risks; for instance political risks especially when reserves of a particular resource are concentrated in one country; economic or industrial significance;

current issues or future, emerging issues; ability to mitigate using technology; and - to a lesser extent - environmental risk or import dependencies. A dozen or more criticality-type studies have been conducted within the last five years, including those by the European Commission, governments of the United States, South Korea, Japan and various EU Member States as well as by companies such as General Electric, Rolls-Royce, Apple and Renault. This research has varied in terms and scope with regard to the country or region, industry sectors, and the types of technology analysed. Throughout this research, however, two common themes can be identified:

- the identification of a list of critical materials based on a filtering methodology; and
- suggested mitigation strategies.

For this work, fifteen reports were selected based on their relevance and their breadth. Each has been examined to understand the methodology used and to determine its applicability to the supply issues facing UK industry, and each takes a different approach.

Options for UK Government and business

The prevailing view is that there are few if any 'scarce' resources, certainly amongst the mineral resources. Mining and production activity responds over time to market pressures and price signals to set levels for what it is economically viable to survey and exploit. The availability of those mined materials is, however, subject to marked geo-political risk, and this forms the major criticality issue to be addressed. Many key manufacturing materials originate in a few locations outside Europe. Worse, the refining and component manufacturing often sit offshore, meaning both supply and recycling channels are not under UK control.

With respect to biotic resources, the key issue will be the absolute availability of suitable land to meet the demands of competing uses of crops. This has been apparent in the Far East in the conversion of plantations, and could be played out in Europe as a biofuels versus food debate. There is also the possible risk, un-quantified at present, of habitat destruction for some small volume high value harvested products for e.g. pharmaceuticals.

Hydrocarbon supplies fall somewhere between the two: conventional oil is becoming more expensive to extract and from ecologically more sensitive areas. On the other hand, large reserves of alternative forms – such as shale oil – appear abundant, though more costly. The immediate threats are most likely, therefore, to be the price impacts and whether UK reserves offer any buffer to these.

The report expands upon these aspects and, in particular, outlines approaches to mitigate the effects of material criticality, including:

- Primary supply structure
- Substitution
- Dematerialisation: use less material to achieve the same level of functionality in a given product.
- Alternative material: replace one material for another without loss of functionality.
- Alternative system: replace one/several components within the same product.
- Alternative products: replace existing technology with different products and/or services.

- Restrict use in other markets: target the use of a critical raw material in a key application, and substitute its use in less critical or more substitutable applications.
- Reuse or recycling.

The report makes specific recommendations for UK Government and businesses with the focus of reducing import dependency and increasing resource efficiency of critical raw materials. Recommendations have been sorted into five key areas:

- primary raw material production;
- substitution;
- raw materials knowledge base;
- waste prevention;
- re-use and recycling; and
- sector-specific actions.

Introduction

The aims of this project

In order to ensure a future of greater material security, the UK Government needs to know the manufacturing industries that will be most affected and the material supply chains at greatest risk. In addressing these issues, this review of existing data has two principal aims. The first is to determine the issues faced by the UK manufacturing industry in the future as a result of possible raw material limitations of supply; the second is to review and assess possible mitigation strategies. Both of these aims are examined for the short term (until 2020) and, where possible, the long term (until 2050). The report concludes with suggestions for action by Government and industry.

Why the project was commissioned

European manufacturing industry depends heavily on imported raw materials, with the EU-25 (pre-2006) importing around 21% by weight of its needs. This makes Europe the world region that outsources the largest part of resource extraction required to produce goods for final demand (Giljum, 2008). In the UK, manufacturing's share of the economy is currently around 10%, and it faces challenges and competition from abroad. Globalisation of manufacturing has resulted in an increasing number of emerging economies competing for a limited pool of resources. Consequently, UK industry faces a growing problem of securing supply chains linked to particular materials.

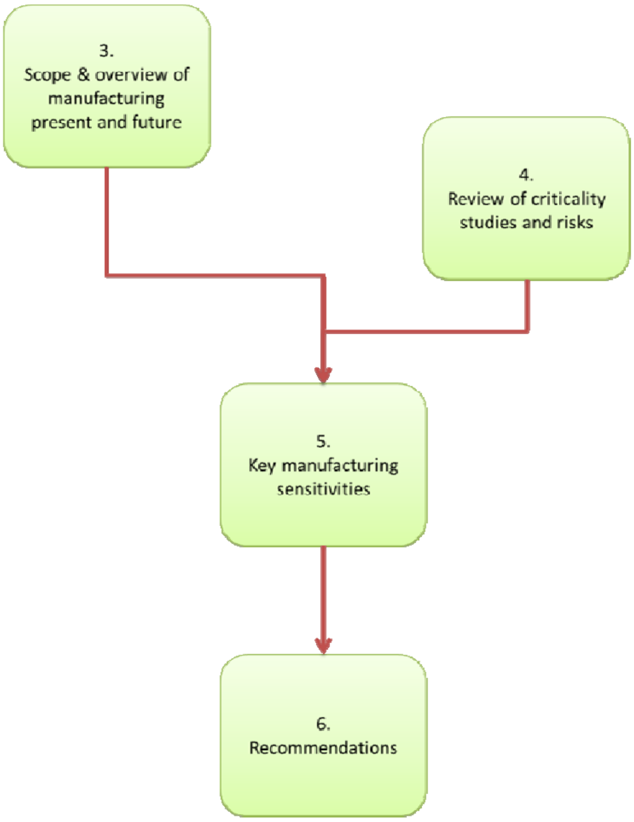
This issue was highlighted in 2010 when China restricted exports of rare earth elements (REEs). REEs are used in many electronic and advanced technology applications and are currently produced by a very limited number of countries, principally China, which produces around 97 % of the global supply. Although research into critical raw materials (CRMs) had already begun, China's announcement has spurred extensive research, both in the UK and globally, to determine which materials are critical for both manufacturing industries and national security. Mitigation strategies to reduce dependence or increase recycling have also been widely investigated. The EU, for example, has identified a list of fourteen CRMs that are crucial for its economy (Critical Raw Materials for the EU, European Commission, 2010). Their critically is due to a combination of high supply risk, high economic importance and high environmental impact.

As well as the threat to current industries, the development of future important industries could also be seriously affected. CRMs are essential for the development of many high-tech and 'green' industries, such as wind-turbines, photovoltaic cells, and hydrogen vehicles. Although it may be possible to develop substitutes for some of them, the requirement for CRMs is likely to remain high. Hydrogen fuel cells, for example, require catalysts made of platinum group metals (PGMs), which are difficult to substitute.

Structure of report

The report has the following structure and its outline is illustrated in Figure 1.

Figure 1: Report structure



Following an initial description of the scope, Chapter 1 identifies the key UK manufacturing industries and the critical materials they use. It then describes the current importance of these industries to the UK economy and the market predictions for growth.

Chapter 2 has two parts. The first is a review of existing literature on critical materials and a summary of those reports most important to this project. The second part identifies specific risks associated with the critical materials identified in Chapter 1.

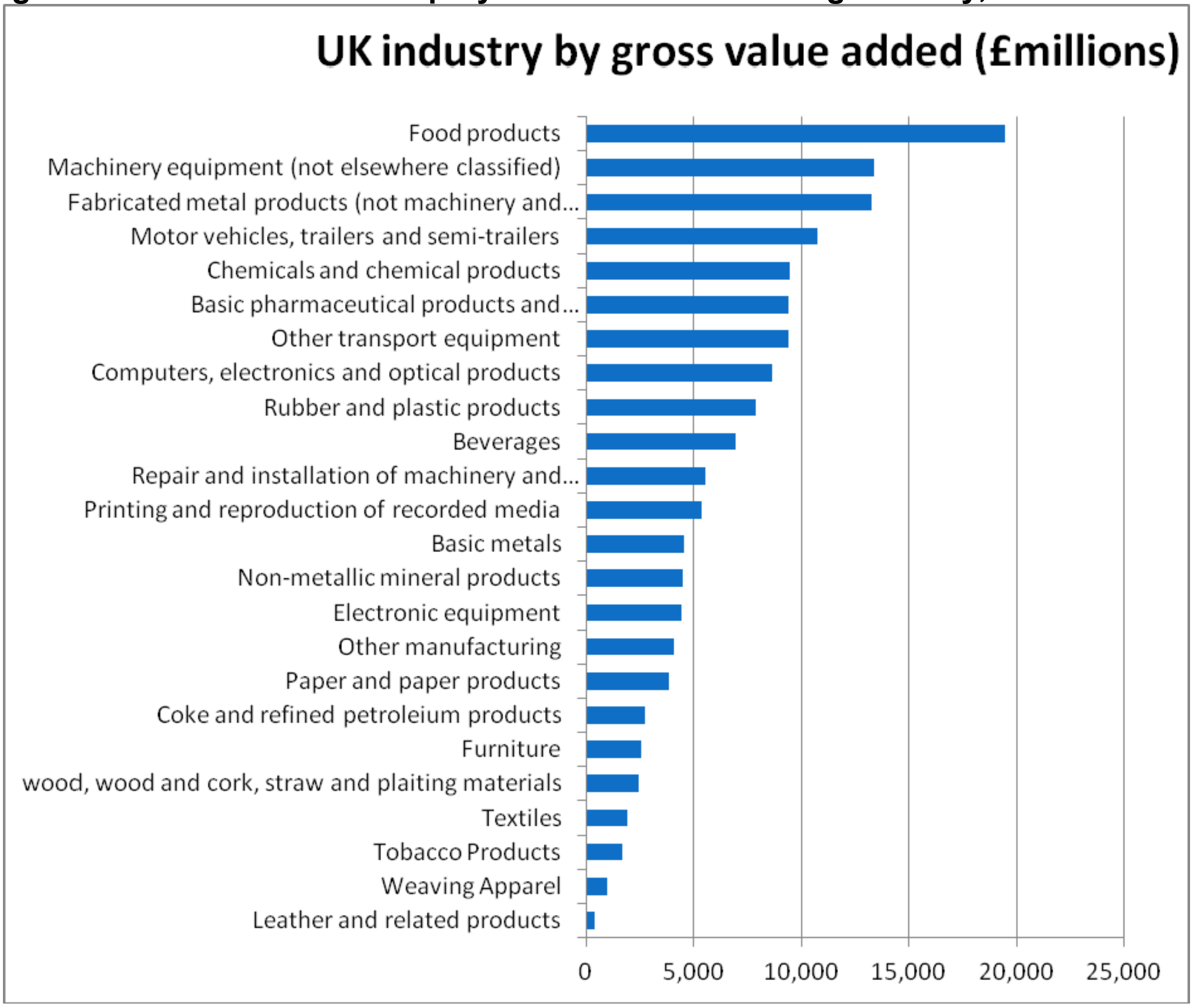
Chapter 3 uses the information from Chapter 1 and both parts of Chapter 2 to identify key manufacturing areas most vulnerable to supply restrictions, and describes the importance of the critical materials to these industries.

Chapter 4 presents the three main mitigation strategies and makes recommendations for future actions.

1. Manufacturing overview

This review aims to identify the UK manufacturing industries that are both important to the UK economy and most vulnerable to supply insecurity. Additionally, it identifies future manufacturing industries that are likely to become important to the UK economy and that could suffer from supply risks. These can be determined using both UK manufacturing data and information obtained from existing reports. Using data from the Annual Business Inquiry for 2011, the value (as gross value added, GVA) of UK manufacturing sectors can be ascertained (Figure 2).

Figure 2: Annual Business Inquiry data for manufacturing industry, 2011



These data provide a starting point for determining those industries most important to the UK economy but must be used in conjunction with more detailed and specific information. What is clear from this table is that the UK's major manufacturing industries are food products, heavy industries - such as automotive manufacturing and machine manufacturing – electronic products, and chemical/ pharmaceutical manufacturing. Food products are out of scope and so have been excluded. Motor vehicles and the aerospace industry are very important to the UK economy and are known to be dependent on PGMs and some REEs. Electronic devices use many critical metals and are predicted to be a growth area, and are therefore included. The chemical industry is also identified as having critical materials dependency. Rubber and plastic products are also both within scope and have been analysed.

However, current economic importance is not the only factor for inclusion. For example, industries that are small now may grow over the next 40 years into important elements of the UK economy. Furthermore, industries as a whole may not be affected by critical materials dependency but there may be adverse consequences for important sub-sectors within an industry.

Previous research has been used to identify further at-risk industries and to refine the list. For abiotic manufacturing, the European Pathway to Zero Waste (EPOW) report “Study into the feasibility of protecting and recovering critical raw materials through infrastructure development in the south east of England” (2011) identified UK industries most likely to be affected by supply limitations of the EU’s list of 14 CRMs. After applying market share and value hurdles, EPOW’s method applied other criticality tests such as for niche applications where a single end-use accounts for over half of the consumption of a particular critical material. This resulted in a shortlist of nine markets:

- automotive and aerospace components (magnesium)
- catalysts (PGMs)
- emented carbide tooling (tungsten)
- chemicals (fluorspar)
- electrical equipment (indium)
- electronics/IT (gallium)
- fire retardants (antimony)
- Photonics (germanium)
- steel and steel alloys (niobium).

There is some convergence between the Annual Business Inquiry data and this list. For the purposes of this review, however; it is also necessary to consider biotic materials, such as rubber, cotton, wood, and non-energy related fossil fuel resources such as plastics. The table below shows the materials identified by EPOW plus these additional materials, together with the usage by most vulnerable industries. Low-carbon industries are also an area of potential industrial growth and, since the EU identifies these industries as central to the reduction of greenhouse gas emissions, they have been included. Table 1 shows the final list of industries and the critical materials they use.

Table 1: UK industries and the critical materials upon which they depend

	Antimony	Beryllium	Cobalt	Cotton	Fluorspar	Gallium	Germanium	Graphite	Indium	Magnesium	Niobium	PGMs	Plastics	REEs	Rubber	Tantalum	Tungsten	Wood
Auto/aero components		X	X					X		X	X		X		X	X		
Batteries			X					X						X				
Catalysts			X				X					X		X				
Cemented carbide tools			X														X	
Chemicals					X													
Construction										X			X		X			X
Electrical equipment						X		X	X	X				X				
Electronics/IT	X	X				X	X		X			X		X		X		
Flame retardants	X																	
Low Carbon Technologies						X	X	X	X			X		X				
Packaging										X								X
Photonics						X	X											
Steel & steel alloys					X			X		X				X				
Textiles				X											X			

2. Review of selected raw materials criticality studies

2.1 Summary of selected reports

Critical materials are typically referred to as those for which there is an actual or perceived lack of availability. This may be for several reasons, including geological distribution, import dependence or competition from a number of sectors. Raw material criticality studies aim to evaluate these and other factors, although the aims and scopes of criticality studies vary significantly. Following China's restriction of the supply of rare earth elements (REEs), the issue of resource security has become of increasing concern both in the UK and internationally. A dozen or more criticality-type studies have been conducted within the last five years, including those by the European Commission, governments of the United States, South Korea, Japan and various EU Member States as well as by companies such as General Electric, Rolls-Royce, Apple and Renault. This research has varied in terms and scope with regard to the country or region, industry sectors, and the types of technology analysed. Throughout this research, however, two common themes can be identified:

- the identification of a list of critical materials based on a filtering methodology; and
- suggested mitigation strategies.

The following summary derives from a review of the different approaches carried out in each report, their scope and context and identifies those aspects most important to UK manufacturing.

Fifteen reports were selected (Table 2) based on their relevance and their breadth. Each has been examined to understand the methodology used and to determine its applicability to the supply issues facing UK industry, and each takes a different approach.

Table 2: Selected critical material reports

No.	Report Title	Author	Year	Source
1	Critical Metals in Low-Carbon Energy Technologies	Oakdene Hollins	2013	EU
2	Resource Security Action Plan: Making the most of valuable materials	Defra, BIS	2012	UK
3	Assessing Metals as Supply Chain Bottlenecks in Priority Energy Technologies *	Oakdene Hollins	2011	EU
4	Study into the feasibility of protecting and recovering critical raw materials through infrastructure development in the South East of England	Oakdene Hollins	2011	UK
5	The EU Raw Materials Initiative - Critical raw materials for the EU	EC DG ENTR	2010	EU
6	Critical Materials Strategy #	US DoE	2010	US
7	Critical metals for future sustainable technologies and their recycling potential	Öko-Institut	2010	UN
8	Minerals, Critical Materials, and the US Economy	US NRC	2008	US
9	Material Security: Ensuring Resource Availability for the UK Economy	Oakdene Hollins	2008	UK
10	Les Nouveaux Metaux Stratégiques	BRGM/ARAMM	2008	Fr
11	Review of the Future Resource Risks Faced by UK	AEA	2010	UK

	Business and an Assessment of Future Viability			
12	Raw Materials for Emerging Technologies	Fraunhofer & IZT	2009	De
13	Reconfiguration of the National Defence Stockpile Report to Congress	US NDS	2009	US
14	Plans for Stable Procurement of Rare Metals	Korean Gov't	2010	Kr
15	Research Priorities for More Efficient Use of Critical Materials from a US Corporate Perspective	GE	2010	US

** Foresight review includes unpublished 2013 update*

 # Foresight review includes 2011 update

Table 3 indicates the coverage of materials within each report without any assessment of the associated risk level.

Table 3: Coverage of materials in the reviews

Report (from	Scope	Territory	Antimony	Beryllium	Cobalt	Fluorspar	Gallium	Germanium	Graphite	Indium	Magnesium	Niobium	PGMs	REEs	Tantalum	Tungsten
1	Energy	EU			X		X	X	X	X		X	X	X	X	
2	General[1]	UK														
3	Energy	EU					X			X		X		X		
4	General	UK	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	General	EU	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6	Energy	US			X		X			X				X		
7	Tech	W			X		X	X		X			X	X	X	
8	General	US					X			X		X	X	X	X	
9	General	UK	X	X	X	X	X	X	X	X	X	X	X	X		X
10	Tech	Fr	X		X		X	X		X		X	X	X	X	X
11	General	UK	X		X	X				X			X	X	X	
12	Tech	Ge	X		X		X	X		X		X	X	X	X	
13	Defence	US	X	X	X	X	X	X		X		X	X	X	X	X
14	General	Kr	X		X		X	X		X	X	X	X	X	X	X
15	Industry[2]	US														

In terms of geographical location the reviews may cover many countries, such as the EU; one country or regions of countries; or they may only consider a single industry. There are also two main approaches for examining criticality. The first is a bottom-up approach, which takes important technology or products as a starting point and determines which critical materials they contain. The second approach is top-down in which, using a list of critical materials, a set of key technologies or products dependent on these materials is identified. The scope of a report may also be restricted to a snapshot in time or may cover a defined time period that may include forecasts into the future.

[1] This Defra report did not provide a list of resources critical to the UK economy.
[2] Data for this General Electric report is proprietary and detailed information of critical metals is therefore not available.

The reports each examine issues of material supply, demand and responses in slightly different ways. In terms of supply the following characteristics are typical: geophysical scarcity, production limitations, supply concentration, political risk, and import dependency. Demand issues include importance to economy or sector, demand growth and price fluctuations. Responses to supply problems may examine substitutability and recycling. Some reports also examine environmental risk.

The EU report *Assessing Metals as Supply Chain Bottlenecks in Priority Energy Technologies*, for example, examines critical materials across the EU for a set of six priority technologies to meet carbon emission reduction targets in the EU for 2020 and beyond. This is therefore an energy-focused report, and it takes a bottom-up approach and covers an area of many countries. It also attempts to forecast future technology requirements and also identifies a set of CRMs with an assessment of the dependence of these technologies on the materials. In terms of supply, the report examines issues of production limitations, supply concentration and political risk. The demand issues cover importance to the EU economy and demand growth. Actions in response, however, are not covered. Despite this, the report is directly relevant to this review as it covers a number of the industries that are likely to be of increasing importance to the UK economy in terms of manufacturing capability and of meeting carbon emission requirements. The industries from this report to consider are: photo-voltaics, wind turbines, smart electricity grids, bioenergy and carbon capture.

The 2010 Defra report *Review of the Future Resource Risks Faced by UK Business and an Assessment of Future Viability* specifically covers UK manufacturing. This report takes a top-down approach, identifying first 27 important resources and narrowing these down to 13 before identifying the UK industries that would be affected by supply chain limitations of these resources. In terms of supply, this report examines geophysical scarcity, supply concentration and political risk. For demand issues it assesses importance to economy and price fluctuations. Substitutability is also analysed.
The EPOW report *Study into the feasibility of protecting and recovering critical raw materials through infrastructure development in the South East of England* looks at a specific region of the UK and is structured toward understanding the existing recycling and recovery of critical raw materials in key UK industries. This report used the EU list of 14 critical materials and identifies a list of products where there are opportunities to recover these materials when the product has reached end of life.

Several key points emerge from an analysis of the reviewed reports. Criticality is not purely a problem of geophysical scarcity but also involve other risks; for instance political risks especially when reserves of a particular resource are concentrated in one country. Many of the studies assess the importance of the material as an indicator of criticality, though the definition of importance can vary and may be defined with reference to a company, a sector or a whole economy. Some studies took a static approach, in which the analysis assessed only current risk factors; while others took a more dynamic approach, assessing factors such as potential limitations and demand growth. Some studies also analysed potential responses to criticality, such as substitutability and recycling. Some other issues have not been widely assessed, such as import dependency, price locations, environmental risk and press coverage.

3. Impact of critical raw material supply risks on UK manufacturing industry

This section summarises issues specifically relating to the 18 critical raw materials under review. Following this, there is a review of the present and potential future risks and impacts of these materials on different UK manufacturing sectors.

3.1 Material-specific issues

Antimony

Reasons for the criticality of antimony include the reliance on supply from China, a country with high political risk, and a lack of substitutability for its main use as a flame retardant. It is also important within the UK defence sector. However, antimony is relatively unimportant for UK business, and the products within which it is contained – such as plastics used in electronic devices – are often imported and not manufactured in the UK.

Antimony is also found in lead acid batteries, this is a declining use due to substitution and reduction of the percentage antimony content. The process for recycling antimony from lead acid batteries is well established in the UK with the recovered material feeding directly back in to the supply chain.

Beryllium

Only three of the studies list beryllium; two of them identify this element's importance in the defence and electronics sectors. Beryllium is produced primarily in the USA and is not easily substitutable. It is not identified as an immediate supply risk for UK manufacturing, but it is important for some UK industries – such as aerospace – and so its future supply should be monitored. Beryllium is also used extensively in the nuclear industry.

Beryllium can be a difficult metal to recycle due to the high toxicity of many beryllium containing chemicals. Additional health and safety requirements mean that reprocessing is only undertaken by specialist refiners. At present beryllium is only recovered from pre-consumer scrap and not from post-consumer scrap.

Cobalt

Around 40% of cobalt is produced in the Democratic Republic of the Congo and therefore has associated political risk. Although there is little immediate supply risk, there are long term risks up to 2050 and the supply of cobalt should be monitored.

Due to its high cost, cobalt is extensively recycled and in 2010 the end of life recycling rate of cobalt was estimated to be 68% (European Commission, 2010). Recycling of pre-consumer cobalt is common in most uses; post-consumer recycling is focused on three applications: batteries, alloys and catalysts (Buchert, 2009). Cobalt is also extensively recovered from the reprocessing of tungsten carbide tools.

Cotton

There has been increasing concern over the environmental impact of cotton production. More than 100 countries produce cotton, with the largest producer, China, producing around 24% of global supply. Owing to the diversity of supply, political risk is not a great factor in possible criticality. However, increasing global demand may affect price stability and result in increased costs. The textile industry in the UK primarily uses cotton that has already been spun and woven into fabrics, so supply risk does not included unprocessed cotton. Most research in materials criticality has focussed on metals and minerals and so there is little information available regarding the UK dependence on imported cotton products, or the level of criticality.

Fluorspar

Although China is the largest producer of fluorspar (59%), the EU obtains only 27% of its supply from China. A further 25% is obtained from South Africa and 24% from Mexico. The supply is therefore not limited to one producer. Fluorspar is important within the chemicals sector; it is the raw material on which most of today's fluoro-chemical industry is based, its main applications being in the production of fluorocarbons for refrigerants and foam blowing, and of flux for primary aluminium manufacturing.

The other important use of fluorspar is as flux in steel manufacturing. Smaller amounts of hydrofluoric acid from fluorspar are used as reagent in the pharmaceutical, agrochemicals and fine chemical industry, or as etching agent in the electronics industry. Fluorspar is defined as near-critical and should be monitored for future supply risk.

Direct recycling of fluorspar is usually not feasible as it is rarely used in its mineral form in the end product. However, for some applications such as refrigerants it is possible to recycle the end products if different types are partitioned at the de-pollution stage.

Gallium

Gallium is used in semiconductors for integrated circuits, laser diodes, photo-voltaics and LEDs. Most gallium is produced in China (32%) with some also in Germany (19%). Gallium is not currently identified as critical for the UK economy.

At present there is no post-consumer recycling of gallium as there is not a large scale feedstock available. However, pre-consumer recycling of gallium is well established and 78 tonnes per annum is recycled (Oakdene Hollins, 2011).

Germanium

Around 71% of germanium is produced in China, so there is a significant political risk for this metal's supply. It is used primarily in fibre optics, infrared optics, catalyst polymers, and is an important material for photo-voltaics and thermoelectric devices. Demand is projected to increase at 3.4% per annum. Currently germanium is not identified as critical for the UK economy, but if the use of germanium by UK industry expands it should be monitored for future supply risk.

Approximately 30% of total germanium consumed is recycled; around 60% of this comes from the manufacture of optical devices. Pre-consumer recovery also covers fibre optics and photovoltaic panels. At present post-consumer recycling of germanium is limited as many germanium containing products are yet to enter the waste stream.

Graphite

China produces around 71% of world supply and so there is an associated political risk. However, there is high global availability of graphite and so little attention is given to the recycling of this material. Graphite has a broad range of applications including steel manufacturing, foundries, batteries and brake linings. Graphite demand is predicted to grow by 3% per annum. However, it is possible that some of this demand can be met by synthetic graphite. Future use of graphite may be in the production of graphene, although some current methods of graphene production do not require graphite so it is difficult to predict the increase in future demand from the development of a graphene industry. Currently graphite is not identified as critical for UK industry.

At present, recycling of graphite from old scrap is very limited and only occurs for a few applications of graphite. A lack of economic incentive combined technical challenges has stalled the market for recycled graphite. As such there is little to no information available on the global quantities and values of recycled graphite. However, there is a growing market for recycled refractory materials for use in products such as brake linings and thermal insulation.

Indium

China produces 50% of the global indium supply and the market for indium is expected to grow at around 6.5% per year. The main source of indium is as a by-product of zinc production. Over 74% of Indium produced is consumed in the fabrication of flat panel displays for which it is an essential element. It is also used in photo-voltaics. Reasons for its criticality include rapidly growing demand coupled with limitations of expanding primary production due to its by-product status, concentration of production in a high political risk country (China), negligible recycling from post-consumer scrap (although pre-consumer recycling levels are high), a lack of substitutability in its main application (flat panel displays) and volatility of prices. Although indium is regarded as a critical material, little UK manufacturing currently uses it. Strong growth in its use is predicted, however, and its supply should be monitored.

The recycling of indium is far from trivial; the process is both complex and energy intensive, consequently recycling levels of indium are low. The spluttering processed employed in the manufacture of flat panel displays is very inefficient with loses of around 85% of indium tin oxide. The lost materials, if recovered are re-used in the process (Oakdene Hollins, 2011).

Magnesium

China produces 77% of the world's supply of magnesium. Around 50% of magnesium is used in casting alloys for automotive and aerospace applications, both of which are important UK industries. A further 16% is used in packaging materials, such as aluminium cans. Annual growth in demand of 7.3% is predicted. Currently magnesium is not identified as supply risk for UK industry but, because of its importance in aerospace alloys, its supply should be monitored.

The technology and industry for magnesium are well established in Europe and as such the recycling rates for this metal are high. Magnesium is mainly recycled by re-smelting its alloys, most commonly with aluminium; the recycling rate is estimated to be 33% of consumption (Oakdene Hollins, 2011).

Niobium

Niobium is produced primarily in Brazil (92%) with most of this coming from a single mine.[3] It is used mostly in automotive steels and also for super-alloys in aircraft, which account for 28% and 8% of world consumption respectively. Both of these industries are important to the UK economy. Niobium is used as an alloying element to strengthen high-strength-low-alloy (HSLA) steels as a micro-alloying component to improve the surface quality. Typical applications include car bodies, wheels and structural members for automobiles and trucks. A demand growth of 10% per annum is predicted. Niobium recycling occurs most commonly in the steel industry, whereby niobium-containing steels are recycled in processes with other types of steel. However, there is no evidence to show that niobium-containing steels are separated out and recycled separately.

Platinum group metals

There are six PGMs: ruthenium, rhodium, palladium, osmium, iridium and platinum. Of these, platinum is the most important for industry where they are primarily used as catalysts. A review of the literature shows that PGMs are regarded as highly critical. They are used as catalytic converters in automobiles and restriction in their supply would therefore have a detrimental effect on the UK automotive industry. In addition, they are currently essential as catalysts in fuel cells and so their restriction would have an impact on the development of this potentially important low-carbon industry in the UK. PGMs have been designated as having a high supply risk due to the concentration of reserves and production in a single country (South Africa). On the demand side, there is a lack of substitutability in their major and economically important application of catalysts (automotive and chemical) and an importance to the defence sector. PGMs are an important supply risk for UK industry.

Because of the high intrinsic value of these metals, both pre- and post-consumer recycling of the platinum group metals is common. There are well established processes Recycling of pre-consumer PGM scrap and these are often operated in closed-loop. However, due to the high level of dispersion in products, post-consumer recycling rates are far lower.

Plastics

In 2011, plastics manufacturing turned over around £18 billion in the UK. However, little research has been carried out into the criticality of plastics. Plastics are most commonly derived from petrochemicals and so are depend primarily on the supply of petroleum, principally in the form of crude oil. The supply of petroleum is diversified, with major producers being Saudi Arabia (12%), Russia (12%) and the USA (11%). Many other countries also produce petroleum, which partly mitigates political risk. However, future concern for plastics is likely to coincide with concern over oil reserves and the possibility of declining or plateauing oil production owing to their depletion.

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[3] Mineral Commodity Summaries: Niobium, USGS, 2011

Rare earth elements

All the studies examined have included REEs in their analysis. They are of key concern for both current high-technology devices and the development of future technologies that may become important for UK industry. China is by far the largest producers of REEs, accounting for 97% of world production. Reasons for the criticality of REEs include limitations of expanding primary production, high demand growth with a lack of substitutability for these applications (magnets, phosphors, catalysts etc.) and negligible recycling of scrap. Concentration of production in a high political risk country (China) is also commonly cited, particularly noting the recent reduction in export quotas. Demand for REEs is predicted to increase by 9.8% per annum. REEs are widespread in high-tech applications so any supply restrictions could negatively impact UK manufacturing.

In general, the recycling and recovery of REEs occurs at a very low level, with most activity related to pre-consumer waste. The recycling of REEs from post-consumer scrap is difficult, partly due to the nature of the products and high levels of dispersion of the materials (Oakdene Hollins, 2011). At present there are no facilities for recovery of REEs from post-consumer scrap in the UK.

Natural Rubber

The EU and the UK depend heavily on imported natural rubber from South East Asia. Natural rubber is used primarily in tyres, which account for up to 75% of usage, but is also used in a broad range of other products from latex gloves to adhesives. According to the Tyre Industry Federation, the UK has a prominent tyre manufacturing industry and produces around 15 million tyres per year for cars, trucks, vans, motorbikes and aircrafts. Despite its importance, studies have not focussed on this material and so there is little detailed information available. Primary research needs to be carried out to assess the UK dependence on rubber, its level of criticality and mitigation strategies.

At present it is not technically feasible for tyres to be closed loop, as material recovered from end-of-life tyres cannot be used to manufacture new tyres. Collection rates for end-of-life tyres are high in the UK; the tyres are either consigned to landfill, energy recovery, materials recycling, re-treading or reuse. Recycled rubber from tyres is used in products such as sign posts, dustbins and flooring.

Tantalum

Australia is the largest producer of tantalum (48%), followed by Brazil (16%) and Congo Kinshasa (9%). The major use for tantalum is in metal powder (40%), super-alloys (15%) and tantalum carbide (10%). Tantalum is important for UK industries such as aerospace. Post-consumer recycling of tantalum is limited to between 1-9% of total consumption. Post-consumer scrap tantalum is found in cemented carbides and aero-engines (European Commission, 2010). The recovery of tantalum from post-consumer electronic scrap is challenging and therefore does not occur at present.

Tungsten

China produces 81% of the world's tungsten and so there is an associated political risk. Around 20% of tungsten is used in cemented carbides. Reasons for concern include a relative lack of substitutability in its major applications, an importance to the defence sector and high volatility of prices. Forecasts predict an increase in demand of 4.9% per annum.

Tungsten is widely recycled and approximately 33-34% of demand is met from recycling. Tungsten is commonly recovered from cemented carbide scrap (Oakdene Hollins, 2011).

Wood

The UK imports small but significant quantities of tropical hardwood from Africa, South East Asia and South America. Similarly to rubber, however, criticality research has not examined this material and so there is little information regarding its importance to the UK economy and its level of criticality. Although at present there is little use of biomass fuel in the UK, this may change and by 2050 and increased competition for wood as a biomass fuel may give rise to tighter supply and higher wood prices.

3.2 Sector specific issues

In the medium- to long-term (20+ years) the demand for critical materials is predicted to increase. Reasons for this include population growth, increasing global economic development and the movement toward low-carbon technologies (Defra, 2010). In addition, a number of technologies and applications have been highlighted as growth areas with critical materials implications (GOS, 2012). These and other sources have informed the following commentary.

Aerospace

Current impact of critical materials

The UK has a thriving aerospace industry that is the second largest in the world. Good growth is anticipated in the short term (Defra, 2010). The UK manufactures both military and civil aircraft and also manufactures components such as jet engines, fuselages and aircraft wings.

With the exclusion of REEs and PGMs found in electronic components, seven critical raw materials are used within the aerospace sector. Jet engines are the largest single user of rhenium; it is used in nickel-based super-alloys for combustion chambers, turbine blades and exhaust nozzles. Rolls-Royce jet engines, for example, require 28% of the world supply thus leaving it vulnerable to supply restrictions.

Cobalt, niobium and tantalum are all used in varying quantities within nickel-based super-alloys for jet engines. Cobalt used in super-alloys represents 22% of world cobalt consumption, and aerospace is the largest market for these alloys (Oakdene Hollins, 2011). Yttrium is commonly used as a coating for turbine blades to increase thermal resistance.

Beryllium copper is found in aircraft landing gear, where it is principally used in brakes due to its non-sparking properties. For military aircraft the brakes are often made of 100% beryllium. For civil aircraft, the operating conditions are less extreme so beryllium alloys are employed.

The aluminium alloys used in aircraft contain magnesium, typically as 1-2% of the composition. Such alloys form a large proportion of an aircraft's weight; in the case of the Airbus A380, the wings of which are manufactured in the UK, they constitute over 70%.

Natural rubber is used to manufacture tyres for aircrafts and the UK is import dependent on natural rubber. At present, it is not possible to manufacture aircraft tyres entirely from synthetic rubber.

Potential future developments

In 2012, the UK had a 17% share of global market in the aerospace industry revenues, employing more than 100,000 people and making it the largest in Europe and second only to the US worldwide (Bardens, 2012). The UK aerospace industry currently has a turnover of around £20 billion and this paper highlights the strong industry outlook for future growth. The UK has particular expertise in the manufacture of the most complex parts of the aircraft, such as turbines, wings landing gear, actuation, avionic fuel and power supply. Global growth in civil aircraft is forecast at 4.8% annually up to 2030 (Reach for the skies, Aerospace Growth Partnership, 2012). The demand for critical raw materials for UK aerospace sector is set to increase and mitigation strategies should be sought for the most critical of these materials.

Advanced composite materials are an emerging technology with significant use in the aerospace sector; the demand for composite materials in the aerospace sector is expected to grow by 15% each year (Lucintel, 2009). It is likely that graphite will be a feedstock for some of these materials.

Automotive

Current impact of critical materials

Every year the UK transport market uses around 150,000 tonnes of aluminium (EPOW, 2011). Some of the main applications include engine and transmission parts, suspension parts, chassis and wheel rims. As with the alloys for aerospace, automotive aluminium alloys typically contain around 1-2% magnesium.

Niobium is used in automotive alloys to produce high-strength low-alloy steels to improve surface quality. These are used for car bodies, wheels, and structural members. In these alloys niobium comprises around 0.1% of the steel. Graphite is used in brake linings for HGVs but forms only a small part of the global graphite market.

The 2012 global sales figure for automobiles was around 84 million, and is expected to reach 100 million by 2020. In the long term – from 2020 onwards – a shift toward new drivetrain technologies is predicted, with an expansion in the use of hybrid, electric, fuel-cell, hydrogen, and flex-fuel vehicles. Although it is not possible to predict which, if any, of these will come to dominate the automotive market, the potential supply risk for critical metals can be identified.

Critical raw materials including rare earths are found in many applications within low-carbon vehicle technologies. Examples include cerium and lanthanum in fuel additives and rare earths in LCD screens and electric motors. There are several different technologies for low-carbon vehicles each with their own raw material demands. In the short to medium term mild hybrid, full hybrid and range extended hybrid vehicles are likely to be the most important but, in the mid to long term, battery electric vehicles and fuel cell vehicles will gain a significant market share.

Fuel cell vehicles PGMs, particularly platinum, are currently a requirement for low-temperature fuel cells where they function as catalysts. Other critical raw materials required for fuel cell vehicles include REEs for the electric motors, as well as graphite and cobalt for li-ion batteries.

Typically either lithium-ion or nickel metal hydride batteries are used a power source for electric vehicles. These battery types require REEs (lanthanum, cerium, neodymium and praseodymium), as well as cobalt and graphite. Using Deutsche Bank forecasts, cobalt use in electric vehicles to 2030 is expected to represent 2% of world supply. However, there is growing evidence that cobalt in batteries is being phased out in favour of cheaper materials (Darton Commodities, 2010). The supply of REEs is a particular concern because of dependence on China for supply. The direct risk to the automotive sector depends on whether car or component manufacturers import raw materials to make parts or whether they assemble imported parts. At present permanent rare earth magnets are the dominant technology used for drive motors in all types of electric vehicles. These motors contain significant amounts of rare earth elements, for example a typical hybrid electric vehicle contains around 1kg of neodymium in the drive motor, not taking into account all the auxiliary motors such as those used to power electrical window lifts.

Potential future developments

This sector includes the manufacture of motor vehicle bodies, parts and electronics. The UK automotive industry is the sixth largest in the world and had a turnover of around £50 billion per year or £10.7 billion GVA in 2011, an increase from £9.9 billion in 2008. There are more than 40 automotive producers in the UK and several thousand component suppliers. In 2012, global sales of automobiles were around 84 million and are expected to reach 100 million by 2020 which, coupled with an increasing population, could result in still further increases in vehicle numbers on the road. More importantly, UK manufacturing and export has been resurgent in recent years (Deutsche Bank, 2008a).

Current projections are that conventional internal combustion engines remain dominant accounting for around 80% of all powertrains up to 2020 (Holweg, 2009). In the longer term other forms of powertrain are likely to prevail, with the further development of hybrid, electric, fuel-cell, hydrogen, and flex-fuel vehicles. However, it is not possible to predict which – if any – of these systems will come to dominate the automotive market, and it is likely there will still be a mix of different systems.

Nissan has recently started to manufacture their fully electric vehicle, the LEAF at their plant in Sunderland. In addition to this Toyota also manufacture the hybrid Auris in the UK as well as all the components for this vehicle. There is evidence to suggest that the UK manufacture of low-carbon vehicle technologies such as these will continue to grow. Mitigation strategies are required to ensure that any future raw material supply chain risks for low-carbon vehicles are avoided.

Batteries

Current impact of critical materials

One of the key developments in this market is the continuing rise of rechargeable batteries; this has in part been driven by the growing market for mobile technology such as smart phones and tablets. These new battery technologies may also be used to balance the contribution to the grid from renewable energy technologies and provide local electricity storage for micro-generation. There are three main types of rechargeable battery which are currently in use these are: lithium-ion, nickel metal hydride and nickel cadmium. These batteries contain a variety of critical raw materials depending on their cell chemistry.

Most types of primary batteries such as zinc carbon contain graphite. Li-ion batteries contain graphite and cobalt; NiMH batteries contain rare earth elements and cobalt; lead acid batteries contain antimony. Usage of Li-ion and NiMH batteries has grown as new markets – such as electric vehicles – have developed.

Potential future developments

The overall manufacturing of batteries and accumulators in the UK has a turnover of £428 million. Currently NiMH batteries constitute 70% of the hybrid electric vehicles market, and Li-ion 30%. Growth estimates for Li-ion batteries are around 16% per year until 2015. However, predictions for battery type usage in hybrid electric vehicles to 2030 (Deutsche Bank, 2008a) suggest that the share of Li-ion (or the emergent Li-air technology) will rise to 100% and NiMH fall to 0%. Currently Li-ion batteries dominate the markets for battery electric vehicles and plug-in hybrid electric vehicles, and this is not expected to change, though it is anticipated that the cobalt content will be phased out.

Most UK manufacturing of these batteries involves the assembly of cells manufactured elsewhere and imported to the UK. However, due to transport restrictions for Li-ion batteries, in the mid to long term UK based manufacture of these batteries is likely to increase. There is a strong UK capability for novel battery technologies as a significant amount of research and development in this field happens in the UK.

Catalysts

Current impact of critical materials

Catalysts are substances which increase the rate of a specific chemical reaction without being consumed by the reaction. They are widely used in the chemicals and the automotive industries, in the latter within catalytic converters. Process catalysts used in the chemicals industry include germanium in plastics production; PGMs used in chemicals manufacture; and cobalt, PGMs and REEs used in the petrochemicals industries. Use of catalysts is strongly linked to growth in the industries that use them. However, the expansion of the market for fuel cells will lead to greater demand for PGM catalysts in particular.

Potential future developments

Platinum use within fuel cells represents an important material requirement for the planned route to decarbonisation of EU energy sector. Approximately 7% of the world's platinum supply in 2030 could be required for fuel cells in the EU. The impact this has on UK industry will depend on the development of UK fuel cell manufacturing. The use of critical metals catalysts in the chemical and pharmaceutical industries should be monitored in order to identify any potential supply bottlenecks.

Cemented carbide tools

Current impact of critical materials

Cemented carbides are also known as 'hard metals' and are a range of composite materials incorporating hard carbide particles held together by a metallic binder. They are used in a very wide range of industrial tooling. Both of the main components of carbide tool – tungsten and cobalt – have been identified as critical materials by the European CRM report. Excluding recycled material, it is estimated that some 60% or 36,600 tonnes of tungsten and 13% or 11,400 tonnes of global cobalt consumption are used in cemented carbides (Critical raw materials for the EU, EC, 2010).

Potential future developments

The functional performance of carbide tools will ensure buoyant demand for tungsten in the foreseeable future, despite some loss of market share in some applications to advanced ceramics. Net raw material demand could be reduced by expansion of closed-loop tool-bit use, where products are returned from the field for remanufacture and re-use. If fusion technologies prove feasible and are implemented, a significant demand for tungsten hard-metals in reactor liners may arise.

Chemicals

Current impact of critical materials

In 2011, the UK chemicals industry had a turnover of around £40.5 billion, with a gross value added of £9.5 billion; this is a slight decline from 2008 levels of £41.9 billion and £10.2 billion respectively. Chemicals are produced for a wide range of other industries, and so demand for chemicals is likely to follow general economic trends in the UK economy and global economy. Chemicals and pharmaceuticals are highly dependent on oil as a feedstock together with a range of other materials incorporated into products and used in production. For example, fluorspar is wholly imported for the manufacture of hydrogen fluoride, itself a feed for fluorocarbons and a chemical reagent; antimony trioxide is incorporated into plastics as an adjuvant for flame retardants; platinum group metals in particular and magnesium to a lesser extent are critical for catalytic actions in refining and bulk chemical manufacture, and synthetic chemistries supporting the pharmaceutical industries.

Potential future developments

Chemicals and pharmaceuticals manufacture is expected to remain a core competence for the UK, hence a continuing dependence on oil and reagent materials either as base materials or intermediates. With the promotion of green chemistries for lower environmental impact, there may be an intensified focus on bio-based feedstocks, but equally on novel chemistries. The impact of these novel chemistries on demands for critical materials cannot be predicted. Rare and/or exotic biota that sometimes exist only in fragile environments, are often used as sources of active compounds in pharmaceutical products. When these cannot be substituted by synthetic compounds, supply chain risk can be created. Little systematic information exists on this issue, which could be important to the UK pharmaceutical industry, and further research is recommended.

Construction

Current impact of critical materials

The UK construction sector had a turnover of around £188 billion in 2011, with a gross value added of almost £70 billion. This is a decline from £223.4 billion (GVA £137.7 billion) in 2008. The construction industry has been negatively affected by the economic downturn and future growth will be dependent on a broader economic recovery.

Potential future developments

The UK Low Carbon Transition Plan15 has set three carbon budgets through to 2050, requiring a 26% reduction of CO2 emissions by 2020, and an 80% reduction by 2050. The construction industry will be required to adapt and contribute to these targets in buildings, energy infrastructure and transport infrastructure. Key technologies highlighted include: fibrous composite materials (conventional carbon and nano-carbon) for longevity and (nano-titanium dioxide, self-healing surfaces) lower maintenance and energy use (coatings); phase-change materials for thermal storage; and bio-based construction systems with lower embedded impact.

Electrical equipment

Current impact of critical materials

Electrical equipment manufacturing in the UK had a turnover of £14 billion in 2011, with a gross value added of £4.4 billion. This is an increase from 2008 figures of £13.4 billion and £4.3 billion respectively. The categorisation used here to determine dependence on critical materials for electrical equipment is based on NACE categories, and is a subgroup of the total electrical equipment manufacture in the UK. This subgroup includes electric motors, generators and transformers, household electrical equipment and other similar items, but excludes any electrical equipment that contains circuit boards.

Potential future developments

This category of goods is likely to show growth related to population with minor effects of technology change

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Electronics and ICT

Current impact of critical materials

The electronics and ICT hardware industries turned over around £20 billion in 2011, corresponding to around £8.6 billion GVA. This is approximately 6% of the total GVA for the UK economy and represents a 22% share of the European market for electronics and IT. The critical materials requirements for the sector include antimony, beryllium, gallium, graphite, indium, magnesium and REEs.

Flat panel displays and touch screen devices are reliant on indium as an element in indium tin oxide, which acts as a transparent electrical conductor. This material is used in very small quantities in thin films, but there is concern over limited reserves and dependence on imports from China.

Current use of critical materials in UK electronics manufacturing is not large, but this area is predicted to grow both in the near- and long-term as new technologies become available, such as those developed by nanotechnology research.

Potential future developments

This market is likely to increase with expanding global population and the increase in wealth of developing countries. It will continue to be characterised by high innovation and the incorporation of highly functional polymers, alloys and semiconductors, the exact nature of which is not predictable. However, these are likely to be the same as currently, but with a different emphasis e.g. on graphene. There is also a tension between light-weighting of products in a class and increasing product diversity and uptake; this means overall material demands will rise for some time to come.

Flame retardants

Current impact of critical materials

Flame retardants are used in a variety of products, including plastics used in electronics, electrical equipment, cabling and flooring, and in textiles. Antimony (as its trioxide) is the only critical material that is widely used in this application.

Potential future developments

There is international pressure to reduce antimony use, but this is likely to be slow given its performance benefits and lack of alternatives. Dependence on antimony either as the trioxide or embedded in intermediates will therefore persist.

Low-carbon technologies

Current impact of critical materials

Low-carbon technologies include industries that could become important to the UK economy. Many of these technologies rely on critical materials to achieve their performance. Wind turbines, for example, rely on powerful neodymium iron boron (NdFeB) permanent magnets. Magnets of the NdFeB type contain 32% neodymium and are consequently heavily reliant on supply of neodymium. Dysprosium is also used in permanent magnets for wind turbines. As a consequence of the Government's Renewables Obligation, there has been a near tripling in installed wind turbine capacity between 2008 and 2012 to over 8GW in 2012. This scheme is planned to run till 2037 so the increase in use of wind turbines is likely to continue, with a consequent demand for neodymium and dysprosium. Currently, however, manufacturing of wind turbines in the UK is small scale and turbines are often imported; unless manufacturing of turbines in the UK increases, there would be little direct negative impact on UK industry if there were supply problems of critical materials.

Fuel cells are devices that use electrochemical processes to generate electricity from various feedstocks, typically with water and heat as the only by-products. The most commonly used feedstock for fuel cells is hydrogen gas. There are several different types of fuel cell, but those that operate at low temperature require catalysts to accelerate chemical reactions. Typically these catalysts are PGMs, mostly platinum but sometimes also ruthenium. Some high temperature fuel cells also use REEs such as yttrium. Fuel cells could be one of the technologies that replaces internal combustion engines and could therefore become an important UK industry. Also, fuel cells have potential to be used in combined heat and power systems (CHP). Such systems using more conventional forms of power generation are well established in other parts of the EU and are becoming increasingly common in the UK. Fuel cell CHP is already available in Japan and emerging elsewhere. If fuel cells become common in both UK automotive industries and power generating industries, this could place increased pressure on the supply of PGMs and yttrium.

Photovoltaic solar cells are expected to contribute up to 12% of European electricity demand by 2020. These solar cells require the critical metals tellurium, indium and gallium for their operating properties. In 2010 solar cells used 91.6% of the world supply of tellurium, 46.8% of indium and 3.9% of gallium. They are therefore particularly dependent on supply of tellurium and indium. However, there is currently little manufacturing of solar cells in the UK.

For lighting, the move to low-carbon technologies involves a shift away from incandescent and halogen lamps towards compact fluorescent lamps and later to LED technology. At present there market for LED lighting is undergoing rapid evolution with many different types of LEDs with differing chemical compositions. Typical LED lamps contain a variety of critical metals such as REEs, gallium and germanium. However, at present UK manufacture of LED lighting technologies is limited.

Potential future developments

The low-carbon technologies most vulnerable to material supply shortage are solar photo-voltaics, wind turbines, fuel cells, fluorescent lights and light emitting diodes (LEDs). Estimates for 2010 show that low-carbon and environmental technologies had an estimated value in 2008 in the region of £112 billion, an increase in 4.3% from 2007. More than half of this is represented by the low-carbon sector, with renewable energy accounting for 29% (£33 billion).

For solar energy the potential raw materials supply risks are heavily dependent on which photovoltaic technology dominates. The EU Energy Roadmap 2050 provides a technology mix within its uptake scenario for solar energy uptake (European Commision, 2011). Looking ahead to the longer term, if the UK were to increase production of solar cells, then supply of critical materials could pose problems for industry.

Photonics

Current impact of critical materials

Optoelectronics are analogous to electronics with the exception that the medium is light rather than electrical current. This sector covers several technologies which are already in use including communications systems, data storage and computer processing, as well as countless emerging applications. Many developed countries are transitioning their digital communication infrastructure from electrical to photonic networks, owing to the substantially higher data rates engendered. A photonic communications link comprises two devices, typically a laser and a PIN diode, to provide translation between the electrical and optical domains, linked by a fibre optic cable.

Photonic devices are specialized, complex and high value semiconductors so their manufacture has not migrated to Asia like silicon electronics. Most companies that manufacture photonic modules are vertically integrated and so some device manufacture is done in the UK. The core wafers are typically III-V semiconductors with silica-based glass used for planar waveguide structures. A multitude of rare and hazardous materials are necessary to manufacture these parts. However, because the quantities consumed are small and the design and process costs so comprehensively dominate those of the materials, the vulnerability of UK manufacturing is limited to cessation of supply.

A fibre optic cable uses a doped silica glass core, roughly 100 µm diameter, to carry the light beam. This is surrounded by a variety of sheaths to ease handling and provide mechanical and environmental durability. The UK fibre optic cable manufacturing industry is expected to achieve revenue of £500m in 2013, with steady growth predicted for the future [IBIS World 2012]. In practice this manufacturing is more of an assembly operation since the majority of the cable constituents, such as the fibre core, metal sheathing etc. are imported as semi-finished parts and moulded together. A variety of readily available and substitutable plastics such as PE, PVC, PVDF and LSZH are used for the moulding. UK manufacturing vulnerability depends on the parts supply chain, which is globally distributed. Germanium is the main critical material used in optical products, where 30% of production is used in fibre optics. Erbium, the rare earth element, is also employed.

Potential future developments

The global photonics market is expected to be worth £1bn by 2022 [PRNewswire 2012]. Graphene – a material in which the UK has some research expertise – offers some promise in optics. An industry based on graphite sources is therefore a possibility in the medium to long term.

Packaging

Current impact of critical materials

In this context, packaging refers largely to aluminium beverage cans although wood and plastics have a significant role. The manufacture of light metal packaging in 2011 had a turnover of £1.5 billion, with a GVA of £342 million, up from 2008 when the figures were £1.3 billion and £308 million respectively.

Potential future developments

For functional reasons, aluminium use should persist although increased recycling may limit virgin demand.

Steel and steel alloys

Current impact of critical materials

In 2011, UK steel and steel alloys manufacturing had a turnover of £7.6 billion and a GVA of £969 million. This represents a decline since 2008 when turnover and GVA were around £8.9 billion and £2.12 billion respectively.

Potential future developments

The future of basic steel manufacturing is unclear, but is unlikely to result in major expansion in the UK. High and performance alloy manufacture is a vital underpinning of key high value manufacturing sectors, and the UK has an excellent technical base and some headline alloy manufacturing, including powder metallurgy. These alloys contain cocktails of critical and non-critical elements, a situation which will persist indefinitely thus representing a continuing supply vulnerability.

Textiles

Current impact of critical materials

Manufacture of textiles in the UK achieved a turnover of £5.5 billion in 2011, with a GVA of £1.9 billion. (Little spinning or weaving occurs in the UK.) The turnover and GVA have declined slightly owing to the economic downturn of 2008, but not significantly.

Potential future developments

Repatriation of textile manufacturing is likely as production costs rise in current Far-Eastern production centres, with the advantage of shorter and more responsive supply chains. In addition, technical and performance textiles (although niche) are a UK speciality and have experienced strong growth. Most textiles or base polymers will be dependent on oil or bio-based feedstocks raising issues of competition for supply.

4. Options for UK Government and business

The prevailing view is that there are few if any 'scarce' resources, certainly amongst the mineral resources. Mining and production activity responds over time to market pressures and price signals to set levels for what it is economically viable to survey and exploit. The availability of those mined materials is, however, subject to marked geo-political risk, and this forms the major criticality issue to be addressed. Many key manufacturing materials originate in a few locations outside Europe. Worse, the refining and component manufacturing often sit offshore, meaning both supply and recycling channels are not under UK control.

With respect to biotic resources, the key issue will be the absolute availability of suitable land to meet the demands of competing uses of crops. This has been apparent in the Far East in the conversion of plantations, and could be played out in Europe as a biofuels versus food debate. There is also the possible risk, un-quantified at present, of habitat destruction for some small volume high value harvested products for e.g. pharmaceuticals.

Hydrocarbon supplies fall somewhere between the two: conventional oil is becoming more expensive to extract and from ecologically more sensitive areas. On the other hand, large reserves of alternative forms – such as shale oil – appear abundant, though more costly. The immediate threats are most likely, therefore, to be the price impacts and whether UK reserves offer any buffer to these.

The following sections take this context and suggest a number of actions in response.

4.1 Mitigation strategies

From a review of the existing literature, several approaches to mitigation strategies can be identified. These fall into three categories: primary supply structure, substitution, and reuse or recycling.

Primary supply structure

For critical materials there is little or no indigenous supply in the UK. However, the UK has free access to EU markets so primary supply could be increased by developing mines within the EU. UK Government should therefore agitate at EU level for exploitation of EU reserves. The EU is pushing for exploration of Greenland's reserves of rare earth elements. However, in many cases the EU does not have large reserves of critical materials and so the alternative is to develop mines outside the EU to diversify supply. Agreements with non-EU countries, such as Chile and Uruguay, have already been signed for access to raw materials. Businesses should, where possible, develop a strategy to diversify their supply of critical materials and also consider stock piling. Another approach would solve the problem in the short term by processing rare earth concentrates from mine waste (tailings) from mines opened outside of Europe. For gallium and tellurium Europe is more self-sufficient and so these pose less of a problem. Both the USA and Japan have recently announced initiatives to find alternative sources of REEs. Japan has begun surveying the ocean floor of the Pacific for new deposits, and the USA has announced the establishment of a new $120 million rare earth research institute to develop new methods of production. According to the US Geological Survey, there may be deposits of REEs in fourteen US States, with California identified as having economically viable concentrations. New supplies of critical materials would diversify their supply chain and so reduce political risk.

Substitution

Substitution of critical materials with other materials is an active area of research and several approaches are possible. The choice of approach will vary depending on the material and the device it is used in. It makes most sense to target materials and applications that are difficult to recycle, or for which there are limited prospects to increase primary supply within Europe. Substitution approaches are as follows:

- Dematerialisation: use less material to achieve the same level of functionality in a given product.
- Alternative material: replace one material for another without loss of functionality.
- Alternative system: replace one/several components within the same product.
- Alternative products: replace existing technology with different products and/or services.
- Restrict use in other markets: target the use of a critical raw material in a key application, and substitute its use in less critical or more substitutable applications.

In order to develop a circular economy in which waste becomes a resource and is fed back into the economy as a raw material, a range of policies which encompass the whole product lifecycle is required. Material resource efficiency is radically improved when increased recycling is combined with greater product longevity, achieved through product design, or repair/reuse/remanufacturing. Recycling and collection targets are already in place in the UK for a wide range of products which coincidentally contain critical raw materials. However, additional targets and measures are required to ensure that critical raw materials are both recovered effectively when products become waste and used in a more efficient way.

Reuse or recycling

Reuse or recycling also includes waste reduction by recycling of post-industrial waste, an area that has seen significant improvement, especially in the areas of magnet, semi-conductor and photovoltaic scrap. Recycling of post-consumer waste is more challenging and, with regard to electronic devices such as mobile phones, does not currently occur in the UK. Some recycling does occur in Europe but is not economic for all of the REEs contained in microelectronics. Umicore in Belgium, for example, recycle critical metals from waste circuit boards. A further possibility is obtaining CRMs from enhanced landfill-mining. This can take the form of extracting metals from mine tailings or mining post-consumer landfill sites for waste goods that contain CRMs. At the moment neither of these activities occurs in the UK, though the Scottish Government is currently considering landfill-mining the West Lothian oil-shale bings to explore whether these contain valuable minerals, though potentials are anticipated to be rather modest. Novel business models and product policies can be effective mechanisms for increasing reuse and recycling and therefore should be further exploited.

4.2 Recommendations

Recommendations for UK Government and businesses with the focus of reducing import dependency and increasing resource efficiency of critical raw materials are discussed below. Key recommendations have been sorted into five key areas: primary raw material production, substitution, raw materials knowledge base, waste prevention, re-use and recycling and sector specific actions.

Primary raw material production

- Increase efforts to encourage greater exploration for and extraction of CRMs from EU countries.
- Quantify potential reserves of CRMs in the UK, such as the reserves of indium in the South Crofty mine in Cornwall.
- Promote efficient extraction and production of metals
- Evaluate possibilities of enhanced landfill mining from mine tailings.
- Explore options for UK based natural rubber production from Russian dandelions
- Encourage international cooperation strategies for acquiring raw materials should be encouraged
- Research into new industrially viable technological solutions for sustainable production of raw materials is required

Substitution

The substitution of a higher risk material with a lower risk material has the potential to significantly reduce the materials requirements for certain sectors, and possibly within a shorter time frame than recovering materials from end-of-life products. Substitution should be considered on a case-by-case basis. Examples of substitution include:

- Dematerialisation of indium in thin film applications, such as in displays and photo-voltaics.
- Alternative systems, such as advanced cooling systems in aircraft to reduce the need for rhenium in alloys.
- For PGMs, substitute catalysts using metal oxides, though results so far have not produced catalysts of equivalent quality to conventional ones.
- Substitution of rare earth elements in permanent magnets used in electric vehicles and wind turbines
- Reduce or substitute critical raw materials in rechargeable batteries
- Minimisation of the thickness of tellurium within thin film photovoltaic solar
- Substitute critical metals from steel alloys and nickel super alloys for less critical metals.
- Substitution or reduction of natural rubber in tyres

Raw materials knowledge base

- Carry out primary research to assess the criticality of biotic materials such as wood, rubber and cotton to UK manufacturing.
- Research the criticality of naturally-derived products to the pharmaceutical industry.
- Produce raw materials flows analyses as part of the process of identifying hot-spots. In particular, this should differentiate the relative dependencies of materials imported

as raw material compared to that embedded within finished or semi-finished components.
- Consider wider risks to availability of critical materials along the supply chain including traceability and provenance issues.

Waste prevention, re-use and recycling

- Encourage remanufacturing and re-use as a means of avoiding dissipation of small concentration materials. This may be assisted by a move to more servicised business models.
- Adopt more sophisticated, differentiated waste recovery targets to ensure that metals such as REEs are recovered from target sources.
- Develop improved or more rapid recycling and recovery technologies, for example, to enable non-destructive removal of high-value parts from electronics within seconds.
- Develop techniques for recovery of technology metals from complex end-of-life products such as electronic and electrical equipment, vehicles, airplanes and low-carbon technology products.
- Devise a coherent set of product policy measures from cradle to grave that address critical resource conservation. These should consider: product policies such as Eco-design standards involving minimisation of critical raw materials, and design for recovery, with associated eco-labels; developing purchasing pulls via green public procurement; increasing producer responsibility measures for end-of-life management to promote value recovery.
- Ban the landfill of recyclable materials such as metals, glass, wood and paper.
- Prevent illegal shipments of waste from the UK thereby preventing losses of valuable raw materials.
- Consider whether on-shore manufacturing in key product sectors should be encouraged in order to bring more of the supply chain into Europe.

Materials-specific actions

Aerospace

The dependence of the UK aerospace industry on geo-physically scarce rhenium is a critical concern. Given that the global growth in civil aircraft is forecast at 4.8% annually up to 2030, there is likely to be a steady increase in demand for rhenium. Attempts should be made to mitigate this risk by finding substitutes, developing alloys that require smaller quantities of rhenium, developing alternative technologies, improving recovery or stockpiling until such a time that supply is diversified or substitutes/alternative technologies are developed. In addition, further infrastructure and capacity is required to cope with the number of aircraft reaching their end-of-life.

Automotive

It is clear that UK based manufacture of low-carbon vehicle technologies such as electric vehicles are on the increase. Investment into the recycling and other end-of-life options is required in the UK, so that critical raw materials can be recovered at a high grade. Currently there are few electric and hybrid vehicles reaching their end-of-life, by 2050 this will not be the case. Some recycling infrastructure is already in place for electric vehicle batteries in the UK, though as this is associated with existing EVs it is on a small scale. Recovery routes occur through the EV manufacturers, who then send the batteries on for reprocessing typically to Belgium or France. At present the main driver for undergoing any form of recycling is legislative due to the requirement for battery manufactures to recycle 50% of their cell materials. This leads to a preference towards treatment type processes which recover low grade materials not suitable for use in batteries.

Rare earth based permanent magnet motors are present in almost all vehicles in varying amounts. To prevent any potential materials supply risks, mitigation steps needed to be taken. Viable strategies for mitigation include securing supply, minimising the use of materials through manufacturing innovation and seeking alternative magnet materials and motor types. At present, there is a significant amount of research effort dedicated to developing alternative motor types for electric vehicles; such research should be encouraged in the UK.

Low-carbon technologies

Between 2020 and 2030, if the development of low-carbon energy technologies progresses as the EU intends, then there will be a strong supply risk for dysprosium, neodymium, tellurium, gallium and indium. Long-term supply of these REEs must be monitored and substitutes researched. For the case of dysprosium and neodymium, where supply is particularly concentrated in China, alternative sources should be found to diversify supply. Government should also encourage – at EU level – the increase of extraction rates of recovery from European copper refiners. This would require relatively small investment. Similarly, there is still much potential to increase gallium recovery from European aluminium refiners, as currently much of the gallium content in bauxite that is processed in Europe ends up in waste streams, with unit capital expenditure being of the order of €20 million.

For low-carbon technologies such as photovoltaic and LED lighting it is critical that policy measures are put in place before products reach there end-of-life to ensure that materials are recovered effectively. Recycling is a cornerstone in ensuring resource efficiency and moving towards a circular economy by recovering valuable resources. However, from many products critical raw materials are not currently recovered and are instead lost during processing. Collection and processing of low-carbon technology products should be established in the UK.

For LED lighting it is not possible to substitute rare earth elements as they have been selected for their special optical properties. Therefore, strategies should be focused on reduction of rare earth elements as well as alternative lighting technologies such as Organic light emitting diodes (OLED) and quantum dot LEDs (QD-LED).

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