IMPORTANCE OF STRATEGIC METALS TO THE GLOBAL ECONOMY

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Global concerns are growing over the long term availability of secure and adequate supplies of the minerals and metals needed by society. Consumption of most metals has increased steadily since World War II and demand is expected to continue to grow in response to the burgeoning global population, economic growth (especially in the emerging economies of Asia and Latin America) and the requirements of new and/or environmental technologies.

Minerals and metals are probably the most important pillar of the global economy - 'if you can't grow it, you have to mine it'. We need minerals for food production (fertilisers, drinking water, food preparation and packaging); energy (fossil fuels, power generation, transmission); construction (houses, schools, hospitals, shops, offices); transport (roads, railways, airports, cars, buses, trains, ships and aircraft); technology and communications (computers, telecommunications, electronic applications); 'green' economy (renewable energy, energy efficiency, low carbon transport).

We produce metals and minerals in very large amounts. In 2009, global mines produced 18 million tonnes of copper, 2.2 billion tonnes of iron ore and 7 billion tonnes of coal[1].

Aside from the major industrial metals such as iron, copper, lead and zinc, we also utilise a group of 'critical' or 'strategic' metals, so called because of their growing economic importance and high risk of supply shortage. They include metals such as antimony, beryllium, cobalt, gallium, germanium, indium, lithium, niobium, platinum group metals, rare earths, rhenium, tantalum and tungsten. In order to assess concerns regarding supply security for the global economy, it is necessary to understand some of their key characteristics and how they differ from other metals and minerals.

KEY CHARACTERISTICS OF CRITICAL METALS

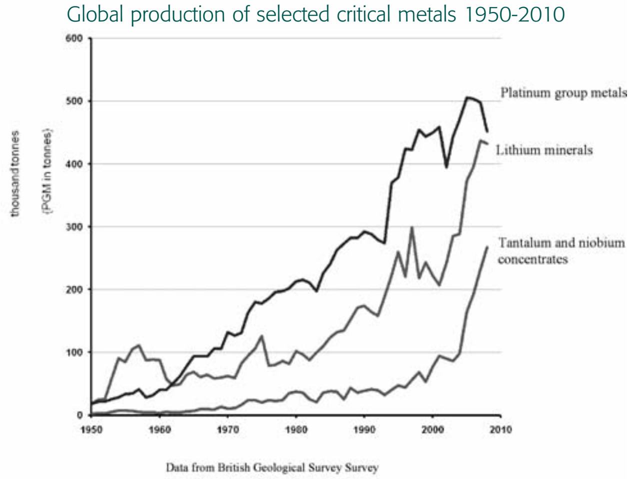
Critical metals have some economic characteristics which distinguish them from the major industrial metals. The volumes of critical metals produced are currently much smaller than for the industrial metals. In 2009, the world produced over 1.2 billion tonnes of steel and almost 40 million tonnes of aluminium, whereas total production of rare earth elements was only 123 thousand tonnes. Global production of platinum group metals in 2009 was only 429 tonnes[1].

Although production is modest compared to industrial metals, consumption rates of critical metals are rising quickly from a very low base (see graph). Drastic changes in production rates over time are illustrated by the fact that, for example, of all the platinum group metals and niobium-tantalum we have ever utilised, 75 per cent has been extracted since 1980.

Compared to industrial metals, and precious metals such as gold and platinum, the size of the global markets for most critical metals is relatively small. With some exceptions, this is currently a disincentive to investment by many of the major mining companies[2]. This situation, combined with concerns related to supply security, appears to be leading towards an alternative approach to maintaining supply by close collaboration between producers and consumers or even vertical integration of mining companies and industrial consumers. This provides certainty for the metal producers and security of supply for manufacturers and is a similar business model to that used by a number of industries including, for example, fluorochemicals.

Another consequence of this lack of economic interest until recently is the fact that their life-cycle in both the natural and anthropogenic environments is poorly understood in comparison to metals such as iron, copper, lead and zinc which we have been using for thousands of years. We know relatively little about the processes by which these metals form, are transported

Global production of selected critical metals 1950-2010



and concentrated in the Earth's crust – vital information if we are to find enough to satisfy demand. We also have a good deal to learn about efficient and environmentally-friendly ways of extracting and processing these metals, as well as in using them efficiently and recycling them effectively when products reach end of life. Compared to metals which have been in long term use, we have a poor understanding of the ultimate fate of many of these more exotic metals when they are released into the natural environment.

Many critical metals are not mined in their own right, but are derived as by-products (or coupled products) from the extraction of 'carrier metals' from ores in which they present in low concentrations. Examples include gallium (found in aluminium ore) and germanium (found in zinc ore). Production from these ore types is predominantly driven by demand for the carrier metal. This factor may constrain any possible increase in production of the coupled product should demand increase independently of the carrier metal.

Although many of these metals are used in small quantities per unit, they perform vital tasks in significantly enhancing the way many industrial products function. For example, the average family car contains just 2-3g of platinum group metals (PGM) in its exhaust system. These metals enable the catalytic conversion of petrol and diesel engine emissions, such that over 90 per cent of hydrocarbons, carbon monoxide and oxides of nitrogen to less harmful carbon dioxide, nitrogen and water Given that 51 million cars were built worldwide in 2009, the environmental and economic benefits of PGM use in autocatalysts are extremely large.

Delivery of other environmental technologies, and particularly those needed to move toward a low carbon economy will require critical metals in some quantities. Major consumers are likely to be renewable energies, such as wind and solar photovoltaics, as well as low-carbon transport modes powered by electricity or fuel cells.

Most wind turbines require considerable quantities of critical metals (principally rare earth elements) in their manufacture. Photo copyright BGS/ NERC.

Recycling, substitution and resource efficiency will be hugely important in meeting the challenge of burgeoning demand for critical metals. However, because demand is rising rapidly we must accept that for the foreseeable future, the vast bulk of our requirements for these metals will have to be sourced from primary resources within the Earth's crust. Most metals normally remain in use by society for 40 to 60 years and the upper limit on what is available for recycling is determined by what comes back from society. By way of illustration, global consumption of copper in 1970 was approximately 8 million tonnes per annum. Five million tonnes was from mining, with 3 million tonnes from recycling. In 2008 global copper consumption was about 24 million tonnes, of which 8 million tonnes were derived from recycling, with the remaining 16 million tonnes from primary production. For most critical metals the ceiling on availability will be much lower because consumption in the past has been very small.

For most other metals recycling provides only 10-20% of demand, although work by UNEP[3] and in research carried out as part of the recent European Raw Materials Initiative[4] suggests that recycling rates for elements such as gallium, indium, tantalum and rare earths are currently less than 1%. Even if recycling rates for these materials were much higher, we must recognise that the critical metal 'resource' currently residing in the anthropogenic environment is very small compared to that needed to meet predicted demand from manufacturers of electric vehicles, wind generators, solar panels and digital devices.

WILL WE RUN OUT OF CRITICAL METALS?

The total stock of metal in the crust is finite, but it is also extremely large. Metals for which we know the precise location, tonnage and which we can extract economically with existing technology (known as 'reserves') are tiny in comparison to the total amount. Concerns that surface periodically regarding physical exhaustion of metals are generally based on a flawed and over-simplistic view of the relationship between reserves and consumption (number of years supply remaining equals reserves divided by annual consumption). This approach ignores the fact that consumption and reserves change continually in response to markets and scientific advances. Reserve levels depend on current scientific knowledge of mineral deposits and target mineral price. As our scientific understanding improves, we can replenish reserves from previously undiscovered resources. Most metals occur in graded deposits: if prices rise, reserves will extend to include lower grade ore; if prices fall, reserves will contract to include only higher grade material. The reality is that despite increasing metal production over the past 50 years, reserve levels have remained largely unchanged[4].

In the longer term, advances in science and technology have improved our ability to find and extract metals. Current reserve and consumption data are not reliable indicators of metal depletion as these figures are closely related to the current state of the global economy and scientific/technological knowledge.

MEETING THE SUPPLY CHALLENGE FOR CRITICAL METALS

Although physical exhaustion of primary metal supply is thus very unlikely, there are no grounds for complacency. Since the beginning of the Industrial Revolution, science has been key to extending our resource base. The classic 'Malthusian' approach failed to appreciate the impact of science on agricultural productivity and access to earth resources. To illustrate this argument in a modern context; mineral deposit types which were largely unknown 50 years ago (such as porphyry deposits which are now the principal sources of copper, molybdenum and rhenium) contribute significantly to global reserves. These were discovered and developed largely as a result of scientific understanding of their metallogenesis derived from research.

However, our knowledge of transport and concentration processes of many critical metals is very poor. Put simply, collaborative science is vital in predicting and finding deposits of these critical metals which to date have been of limited economic interest, but are now being used in rapidly increasing amounts.

The more pressing threats to supply are uneven resource distribution, geopolitics and looming environmental limits. Metal deposits are unevenly distributed across the globe and patterns of supply and demand shift continually. Rapidly increasing demand from emerging economies such as Brazil, Russia, India and China has led to a scramble for access to resources, particularly in the developing world. Economic and diplomatic tensions between those who have mineral resources and/or means of production, and those who have not, are common. Current concerns in western countries regarding China's near monopoly of production of rare earth elements clearly illustrate this.

The likelihood is that tensions over resources will increase over the next few years. It is therefore essential that the UK retains its world class capability to monitor and analyse global mineral production, consumption, trade and reserves(1). This should be done in conjunction with other EU member states, the US and Japan in order to develop an early warning system to better predict future supply problems.

Extraction and processing of metal is energy intensive and carbon emitted as a consequence represents a significant environmental limit to our resource use. Major research and innovation is required in order to break the current link between metal extraction and greenhouse gas emissions. Current examples of where low carbon technology may be heading include in-situ leach mining of metals such as uranium and microbial bio-leaching of metals such as copper and nickel from extracted ores. Such approaches have the potential to significantly extend the resource base by allowing working of previously uneconomic ore types and grades.

Critical metals are vital to the global economy and their importance will grow in the coming decades as we strive to meet the twin challenges of population growth and climate change. In order to mitigate current and future geopolitical and market constraints on supply, we urgently need to carry out research to identify and utilise new resources from the Earth's crust and by recycling material already in our society. Similar endeavour will be needed to break the link between metal extraction and human-induced climate change.

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(1) British Geological Survey (2010) Mineral Statistics home page http://www.bgs.ac.uk/mineralsuk/statistics/home.html

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STRATEGIC METALS - HOW CAN GEOSCIENCE HELP INCREASE RESOURCES? HOW WILL A SUPPLY SHORTAGE IMPACT ON THE UK?

GEOSCIENTISTS – the scientists who locate Geological Resources of Strategic Metals

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THE CRITICAL ROLE OF GEOSCIENTISTS

Geoscientists play the vital role in the discovery of new metal deposits. A strong presence in the Geosciences is possible in the UK as it has an unusually great variety of geology for its land area and we have a long history of mining. Today there is an active extraction industry with the production of aggregates and coal and new ventures such as gold quarrying in Northern Ireland and a world class resource of tungsten to be extracted at Hemerdon in Devon. However inevitably the UK is small and has to source the majority of its metals from overseas. So to secure supplies, traditionally, we have been a world leader in research in metal deposits globally. We still have a great concentration of researchers who, with nourishment and support, have the skills to produce high quality science to improve security of supply of metals and make UK manufacturing more competitive.

METAL SUPPLY

Sourcing metals is essential both to maintain our standard of living and to provide the rare metals necessary to develop a low-carbon global economy. This has been highlighted recently by metal shortage scares such as the REEs. There is now much interest in metal scarcity with publications being produced, for example the recent House of Commons Science and Technology Committee report on Strategically Important Metals (5th report Session 2010-2012). There are sufficient geological resources of metals in the Earth to supply our future needs but this will only be assured if Geoscientists continue to explore for and discover new metal sources worldwide. Indeed their efforts need to increase as the demand for metals is increasing exponentially as world population increases. Giant developing economies such as China and India now desire the metal hungry goods that we, in the western world, take for granted as essential. Unless we plan to secure metal supplies we will be increasingly exposed to shortages as there is a substantial time lag, typically of at least 10 years, between a shortage and the time taken for a new geological source to be developed and brought to market.

GEOSCIENCE ORGANISATIONS

Within the UK we have a very active group of Societies that focus on the Geosciences. The principal Society is the Geological Society of London that hosts within it the Mineral Deposit Studies Group (MDSG). Other Societies include the Institute of Materials, Minerals and Mining (IOM3) and the Mineralogical Society. Exploration for metals by Geoscientists is carried out by companies targeting new ores and many still have their headquarters in the city of London making up about 15% of the FTSE 100. Institutes provide a focus for applied research in this field and include the Minerals Section at the British Geological Survey and the Mineralogy Department at the Natural History Museum. Universities also pursue applied research on understanding ore forming processes and in training students. The UK has exported many exploration geology graduates into this global business of metal sourcing. The MDSG runs meetings that bring together those whose task it is to understand the geology of mineral deposits and so discover new metal supplies. At these meetings students are encouraged to meet industry personnel and build valuable contacts.

GEOLOGY

Metal supply depends on many political and sociological factors as well as the Geosciences. Increasingly also metals are being recycled as, unlike oil, gas and coal, they are not destroyed during use. However natural metal supplies still dominate and these are controlled by the geology. Close to the Earth's surface different metals vary in abundance and concentrate by different geological processes. For example, although rare, gold is concentrated by a multitude of complex geological processes and is widely distributed in different types of geology. Other metals are restricted by their geology as for example platinum with the major deposits located only in RSA and northern Siberia.

PLATINUM: An Example Of Exploration Using Geoscience Skills

Many aspects of the Geosciences can be employed to explore for and secure more supplies of all metals and the approach to explore for more platinum resources can be used as an illustration. The major platinum deposits are located in giant magmatic bodies where there has been extensive deep melting in the Earth producing magma that concentrates platinum as it crystallises into mineable surface deposits. Also there are many marginally economic occurrences of platinum in other rock types. Future exploration will focus on both geology similar to the economic ores and on the many different currently non-economic occurrences. For example a new source is anthropogenic platinum, now accumulating in road dust, due to emission from vehicle catalytic converters. Platinum in road dust is now present at extremely elevated values compared with natural background values. Research has shown platinum is rapidly dispersed as it is washed down drains but it is reconcentrated in acid mine drainage and in incinerated sewage ash. Anthropogenic platinum is in a different mineral form to that of natural ores and attempts to recycle this platinum will require new mineral processing techniques. Therefore investigation of just this one metal requires a whole set of Geoscience skills ranging from understanding magma generation deep in the Earth to the sedimentary processes of collection of waste in the urban environment.

GEOSCIENCE TECHNIQUES

So the Geoscientist needs to decide how and where to search for more sources of metals. This uses a great variety of techniques that range in scale from satellite imagery to sub-micron microscopic studies. Modelling can predict additional conventional and new types of ore. The Geoscientist uses geology, geochemistry, geophysics and mineralogy and needs to adapt and search for new opportunities as for example new rock exposure revealed by deforestation of the Amazon or retreating ice sheets. It is likely that in the future we will need to extract metals from lower grade ores using new extraction and processing techniques.

GEOSCIENCES IN UNIVERSITIES

There are several UK universities with a great tradition and considerable expertise in the Geosciences specifically teaching applied geology for metal exploration. The training is both theoretical and practical emphasising field skills, mapping, making measurements, understanding ore forming processes. Some university Geoscience departments run Society of Economic Geology chapters that keep the students in touch with the international exploration community. Lecturers in universities, who run these applied courses, also carry out research on exploration using high tech equipment currently held in universities allowing in-depth studies that provide valuable insights for metal exploration.

GEOSCIENCE STUDENTS

There is a great demand for exploration geology degrees, often from students who have had some contact with the industry, and/or have often travelled extensively and seen mining operations. They therefore also have some of the many non-science related skills that are necessary for a successful career in the exploration industry, including self confidence, a foreign language, team work skills, including the ability to survive in hostile environments, working in foreign communities where no tourist would venture. The UK has many talented young people who wish to study the Geosciences and go into the metal exploration industry. Graduates return to the UK from all over the world and feed back information on the current state of the exploration industry and metal exploration.

SUPPORT FOR TEACHING AND RESEARCH

Although numbers of students have recently increased substantially the appointment of metallogenesis lecturers has declined. Universities are set goals by Government that tend to exclude the appointment of metallogenesis lecturers because research assessment exercises tend to favour blue sky research. Although Government is encouraging vocational training NERC has just removed funding for MSc courses which affects the Geosciences. Our great British tradition of teaching exploration for new metal sources in universities is being threatened. Research funding for metal exploration is also difficult in universities because of competition for blue sky research funds, the time lost from research due to enormous amounts of time writing unsuccessful research proposals disguised to attract funds from other areas and the funding of short term research. Much research is too applied for Research Councils and not applied enough for companies.

This non-applied research culture is beginning to change. There are indications that the situation is easing as there is a realisation about the potential threat of metal shortages. The next Government inspired university research assessment exercise (REF) contains a section (if relatively small) on the impact of research. We welcome the recent initiative by NERC to ring fence some research funds for ore deposit research.

THE DEBATE

Does the UK want to take an active interest in the supply chain of metals for UK industry, to predict which metals will be scarce in the future and so smooth out metal shortage crises to maintain its competitive edge?

WHAT CAN BE DONE?

• We need to expand Geoscience research to discover new metal sources and processing techniques to secure supply. Government can make subtle changes in policy to strengthen teaching and research in the Geosciences and further encourage scientists to carry out applied research. This is necessary to attract, inspire and educate young geoscientists who can search for metals for our future.

• We need to co-ordinate the monitoring of metal supply to keep a presence on the world stage. It is difficult to predict which metals will become scarce first because experts tend to specialise in one metal and companies plan exploration for 15-20 years ahead for commercial reasons and neither give an overview of future supplies. We (Government, institutes, universities and companies) should establish a network of stakeholders (perhaps through the Societies and Knowledge Transfer Networks KTNs) to bring together individual Geoscience experts for different metals, along with experts in the extraction, processing and manufacture for each metal so that we will be able to identify better specific needs and predict shortages. Such a body would give an overview and would promote collaboration.

There will be increasing competition for metals worldwide and the UK needs to be prepared for this. The UK Geoscience community stands ready to engage and play its part.

STRATEGIC METALS - HOW CAN GEOSCIENCE HELP INCREASE RESOURCES? HOW WILL A SUPPLY SHORTAGE IMPACT ON THE UK?

How will the UK Manufacturing Industry respond to a shortage of Strategic Metals?

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Knowledge Transfer Manager
The Environmental Sustainability Knowledge Transfer Network

BACKGROUND

The development of extractive industries and manufacturing facilities worldwide and the improvements in transport and communication systems has resulted in globalisation of business operations and productive capacities. Product and equipment manufacturers can source their inputs of raw materials and/or components from wherever they can negotiate the most favourable terms. This has resulted in a tendency for businesses to locate basic manufacturing facilities in countries that have a low cost base. Economies with a higher cost base strive to compete through higher productivity and by investing in innovations which often rely on advanced materials and technologies. Manufacturers must now aim for continuous improvements in their productivity, resource efficiency and product performance to remain competitive in the global marketplace. With a complex global supply chain how can UK based industry manage supply risks? According to Kirchain et al[1] "a resource becomes 'scarce' when the effort needed to access the marginal amount of material is greater than the amount of effort one would be capable of or willing to exert".

Globalisation has resulted in extended supply chains that rely on highly efficient logistical management which has been facilitated by modern information and communication technologies. At present there are concerns about the security of supply of some of the strategic metals that are required for the delivery of the advanced technologies (eg aerospace, ICT and renewable energy systems). The 'Just in Time' concept has driven tighter production schedules along the complex supply chain networks of products based on advanced technologies. Companies aim to simplify and streamline their processes, whilst collaborating more effectively with a range of partners, suppliers and clients around the world. In these complex systems it is important to analyse and manage risk. Advanced manufacturers may not be direct purchasers of strategic metals but they must be aware of the value that they deliver to their products and must examine the supply chain risks for their resources.

Manufacturers can reduce supply risks through long term relationships with reliable partners and by securing several sources of supply. A recent EU study[2] on materials that are critical to the European economy has suggested that the risks associated with 14 materials should be carefully considered.

WHY MIGHT SHORTAGES OCCUR?

Concerns about access to resources are not new although over the years the materials classified as 'strategic' have changed. Following the industrial revolution the demand for, and ability to extract, metals grew and nations sought greater access to raw materials through colonisation and/or international trade. Many advances in military technologies have been based on developments in the use of systems and technologies that require specific metals to deliver superior military capability. Therefore access to these metals, and the ability to process them into suitable forms, has been considered to be strategically important. Indeed access to strategic metals has been a significant factor in many military confrontations. The trend towards multinational corporations and globalised supply chains and the end of the 'Cold War' meant that concerns about the military need for strategic metals became less intense.

In the past some analyses considered that the markets for the major metals were mature and saw little prospects for growth in global demand. However these overlooked the discrepancy between the specific consumption rates for materials in economies at different stages of development.

Since industrialisation there has been a tendency for specific material utilisation (kg/person/year) to increase as an economy becomes more affluent. When the growing world population is also taken into account the demand for materials can be projected to grow in the foreseeable future unless there are fundamental changes in consumption patterns.

In addition to the growing demand for 'traditional metals' the special properties of a wider range of elements are now being exploited to create the advanced materials and systems required for modern ICT and low carbon technology applications (PV systems, batteries, motors, magnets, etc).

Due to geological and other factors such as low production costs and the development of specialist knowledge and technologies, there has been a tendency for the production of some of these strategic metals to be dominated by a few organisations or regions (eg Rare Earth Elements and Magnesium in China, tantalum in the DRC, Niobium in Brazil, etc).

Some analysts have combined the demand for a metal with a published figure for reserves and projected when resources will be exhausted. This is really a misunderstanding of the situation. It is far more likely that the cost of extracting materials – in monetary and/or environmental terms – will be exceeded rather than the ultimate depletion of the Earth's resources. The total costs of the energy required to recover a specific metal from primary sources may rise to exceed the value derived from its use or it may become more viable to recover more metal from secondary sources. The development of modern societies has been based on the output of industrialised systems powered by relatively low cost fossil fuels. Based on current trends it has been projected that, since industrialisation, human consumption of fossil fuels will have released one trillion tonnes of carbon (1,000,000,000,000) into the atmosphere by 2045[3]. The scientific evidence suggests that increasing levels of GHGs in the atmosphere pose a significant risk to the ecosystems that provide the resources necessary to support the human population. Hence the global efforts to promote more sustainable development by developing low carbon economies.

The attempts to make parallels between oil and minerals – such as the 'Peak' concept for oil can be misleading. When oil is used as a fuel it is consumed and cannot be recovered or recycled. Metals are, to a greater or lesser extent, consumed or dissipated in some applications (eg magnesium in flares, metals used in sacrificial anodes and metallothermic reduction, zinc in galvanised coatings) but in many others a significant proportion is available in forms that could be recovered easily. In developed economies there is a significant volume of anthropogenic material that is in what has been called the 'Technosphere'[4] – these have been extracted from the Earth and are in use – such as bridges, rails, motor cars, electronic devices, etc, or are available for reclamation. The useful life of metal varies with the application but in effect the material in the 'Technosphere' is an inventory of resources that is available for recovery and re-use.

WHAT CAN MANUFACTURERS DO?

There are many stages in the supply chain between extraction of metal from primary resources and the deployment of the material in a finished product and so manufacturers will need to co-operate with, and rely on, good partners and suppliers.

Perhaps there will always be a degree of tension or balance to be struck between local versus global sourcing, self-sufficiency versus mutually beneficial trade and between short term and long term requirements. All organisations, be they national governments, trading blocks, multinational agencies or small/medium sized enterprises, need to manage risks. Different approaches have been adopted at the national level. The USA has maintained stockpiles of strategic materials but they also aim to ensure that the US economy has the downstream capability to convert these into forms suitable for their strategic (military) requirements. Primary Magnesium producers in Canada, Norway, France and Italy have shut down because they couldn't compete with imports from China. However a primary magnesium producer has survived in the USA because import duties have been applied on material from China. Recent concern about the Rare Earth Metal supply chain has stimulated the re-development of domestic operations in the USA. Japan has retained the capacity to produce significant volumes of primary metals and has a co-ordinated programme to ensure that the materials required for its value added industries is available (through stockpiling, careful monitoring of global trends, investment in global prospecting and extraction opportunities, implementation of their 3R policy and R&D on new development/substitutions). To date there has been no effective co-ordination of resource policy in the EU. Some of the major resource companies are listed on European stock exchanges but they do not necessarily have operations within the EU. Nevertheless some EU based businesses have retained strong connections with primary extraction operations both local and in other parts of the world (Copper, Boliden, Sweden; Nickel & Manganese, Eramet, France-Gabon-New Caledonia). Efforts to develop an EU strategy on raw materials are currently under way.

The UK no longer produces primary copper, zinc, or tin and but has retained primary capacity in steel and aluminium albeit at lower output levels. Specialist capacity exists for processing special metals and recovering alloys from some secondary materials (such as nickel and nickel based alloys, titanium, magnesium, aluminium, Rare Earth & Platinum Group Metals, etc). If the UK is to retain a share of the development of high value added manufacturing it must build on and expand the skill base in materials science. It must invest in the infrastructural developments that recognise the value and benefits obtained from the knowledge gained from producing and converting metals into forms suitable for resource efficient applications (eg through the application of special casting and working facilities, or the production of powders and nano-materials). To do this effectively the UK must enable research groups to develop the critical mass to contribute on a global scale in niche areas associated with primary production (in the UK and globally), the development of substitutes for critical applications and in recovery and recycling. The UK is a net exporter of metallic scrap and whilst this is a source of export revenue it is important that the optimum value is recovered from these resources. Exports of scrap to areas without the facilities to process materials according to global standards of best practice should not be allowed.

Some manufacturers have recognised the value that can be gained from a broader engagement in the life cycle of their products. By engaging with the end-of-life management they can ensure that they can have access to the resources that they need by promoting recovery and recycling. In times of crisis one way of ensuring some access to critical materials has been from those present in the 'Technosphere' – but better management of materials should be developed without waiting for a crisis. This would be a logical approach from the point of resource efficiency and climate change because efficient recovery of secondary materials is usually less energy intensive and has a lower impact on the biosphere than primary recovery from low grade ores (this should be verified by LCA studies for each situation).

If a specific metal becomes very expensive there are strong drivers to investigate ways of substituting alternates. This could be achieved by developing materials that can deliver the same or better cost effective performance (direct substitution) or through the development of a new technology that makes that specific functional need obsolete (indirect substitution).

Commercial and military organisations will have different perspectives on strategic metals. If the UK Manufacturing Industry is to be competitive in the global market all stakeholders (Government, OEMs, Tier 1-n suppliers, raw material suppliers, recyclers and end-users) must participate and collaborate in risk management programmes. These can reduce the risk of shortages of critical materials. The UK should align with European programmes and ensure that it has the world class research and industrial production capability to participate in important sectors. These should include the development of primary resources, the development of substitute materials/technologies and the development of recovery and reprocessing systems. If all of the stakeholders in the supply chain collaborate to address these issues the potential for price spikes will be reduced. It would also be prudent for each organisation to conduct risk assessments to determine the nature of their exposure to short, medium or long term disruptions in the supplies of strategic metals.

The legend of King Midas illustrates how access to even a precious metal is of little value without the knowledge or capacity to convert it into a useful form. Measures to encourage UK manufacturers to engage in sustainable materials management systems throughout the supply chain would make a significant contribution towards establishing a 'green economy' in the UK and across the globe.

(1) http://dspace.mit.edu/handle/1721.1/35728

(2) http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm

(3) http://trillionthtonne.org/

(4) www.mdpi.com/2071-1050/2/5/1408/pdf