www.defra.gov.uk

A Review of National Resource Strategies and Research

March 2012

Department for Environment Food and Rural Affairs

This document/publication is also available on our website at:

http://www.defra.gov.uk/environment/economy/

Any enquiries regarding this document/publication should be sent to us at:

Department for Environment, Food and Rural Affairs

Nobel House

17 Smith Square

London SW1P 3JR

Telephone 020 7238 6000

Website: www.defra.gov.uk

PB 13722

Contents

1. Introduction

Maintaining and developing the UK economy and its industries relies on a steady supply of raw materials, both biotic and non-biotic. The issue of resource security has come to the forefront of debate over recent years, partly due to considerable concern over the security of supply of so called ‘critical’ materials, with rare earths attracting the greatest attention in the press. The EU defines critical materials as ‘economically important raw materials which are subject to a higher risk of supply interruption’[1]. Some of these critical minerals and metals are genuinely rare, while others are more abundant. However, there is actually no real issue of physical scarcity for the majority of these materials, at least not for the next century or so. What makes these materials critical for the UK (and many other nations around the world) is a lack of their domestic production. UK businesses and industries are almost completely dependent on their import, while at the same time the market for these materials is ever expanding. For example, many are used in a number of technological innovations, including some new green energy technologies such as hybrid and electric vehicles, wind turbines and photovoltaic panels. Table 1 shows which critical materials are used in these, and other technologies. However, issues of resources security are likely to encompass a range of materials across other sectors.

Although all of the elements are found in the earth’s crust, their concentration varies. One of the key issues with these critical materials is their geopolitical concentration. Viable deposits are concentrated in a very small number of countries, a situation very often compounded by the fact that these countries are associated with political and/or economic risks. The rare earths make a good example since over 95% of global rare earth production is currently taking place in China and in recent years China has imposed export tariffs and quotas for these materials.

An additional problem facing these critical materials is that their markets are prone to speculative manipulation, which can cause price spikes and make supply even more difficult. This is a result of the fact that they are not traded on transparent markets like base metals (like copper, zinc and aluminium) but rather prices are set via contract negotiations. What is more, the process from exploration to mining of newly found deposits can take up to ten years, meaning that production cannot immediately increase to address an increase in demand. Furthermore, there is a very high risk associated with exploration activities, as only a handful out of a thousand explorations will actual lead to mining.

The nature of these materials is another factor influencing their supply. The majority of critical materials are found mixed with a number of other elements, and are mined

[1] http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm

as ‘by-products’ or ‘co-products’ of base metals. Separating them out is often quite difficult and costly. Therefore, whether a miner decides to extract these critical materials will depend on whether it is cost effective to extract the base metal in the first place, and to separate the two. Figure 1 shows which base metals the critical elements are found with.

Critical Materials Found in Clean Technologies		
Technology	**Component**	**Material**
Wind	Generators	Neodymium
		Dysprosium
Vehicles	Motors	Neodymium
		Dysprosium
	Li-ion Batteries (PHEVs and EVs)	Lithium
		Cobalt
	NiMH Batteries (HEVs)	Rare Earths: Cerium, Lanthanum, Neodymium, Praseodymium
		Cobalt
PV Cells	Thin Film PV Panels General	Tellurium
		Gallium
		Germanium
		Indium
		Selenium
		Silver
		Cadmium
	CIGS Thin Films	Indium
		Gallium
	CdTe Thin Films	Tellurium
Lighting (Solid State and Fluorescent)	Phosphors	Rare Earths: Yttrium, Cerium, Lanthanum, Europium, Terbium
Fuel Cells	Catalysts and Separators	Platinum, Palladium and other Platinum Group Metals, Yttrium

Table 1 Critical materials and the green technologies they are found in (Resnick Institute, 2011)

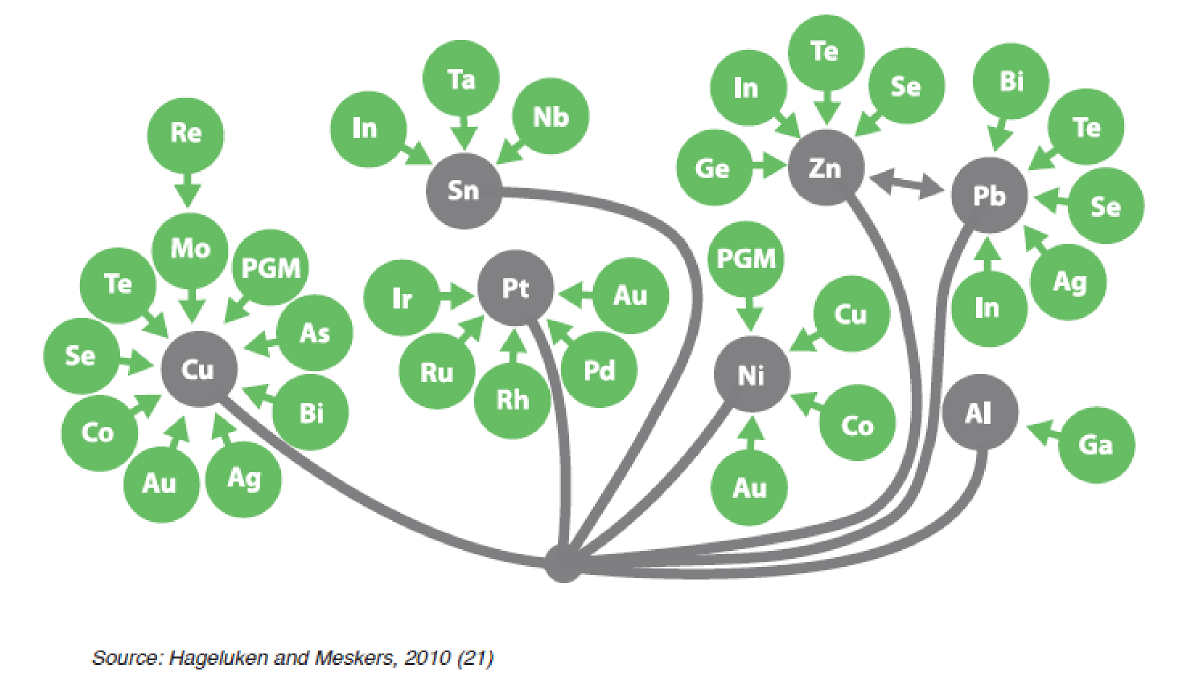

Figure 1 Critical elements produced as by-products and co-products of base metals (Resnick Institute, 2011)

Substituting critical materials with others that are more abundant is one way of addressing the resource security problem, but some of these materials have properties and characteristics that make them uniquely suitable for specific applications meaning that a whole system substitution might be necessary to reduce the use of the critical material. Another possibility would be to recycle these materials as a means of reducing dependency on virgin sources. However, as Figure 2 shows, the end of life recycling rates for a number of these materials are quite low at the moment, due to the fact that it is not always technologically possible to separate the critical material from other materials in a product. Furthermore, the more recent use of these materials means that most countries lack the necessary infrastructure to collect, separate and recycle them. Finally, as a lot of these materials are used in products that have long lifetimes (such as wind turbines or electric cars), they will only reach the waste stream several years after their production.

Resource security is a global issue and as such many nations around the world have set up, or are considering, strategies to ensure that in the future they will be able to maintain supplies of these materials for their industries. In general, all the strategies include resource efficiency and waste minimisation measures, but the actual approach taken depends on the specific situation of each country, with resource-rich countries enforcing measures to preserve and expand their deposits and resource-poor countries mainly focussing their efforts on recycling and substitution.

The UK Government has developed an Action Plan on resource security to ‘assist business with strategic risk management and recovery of resources’. This comprises a range of actions to improve the resource security of the UK economy.

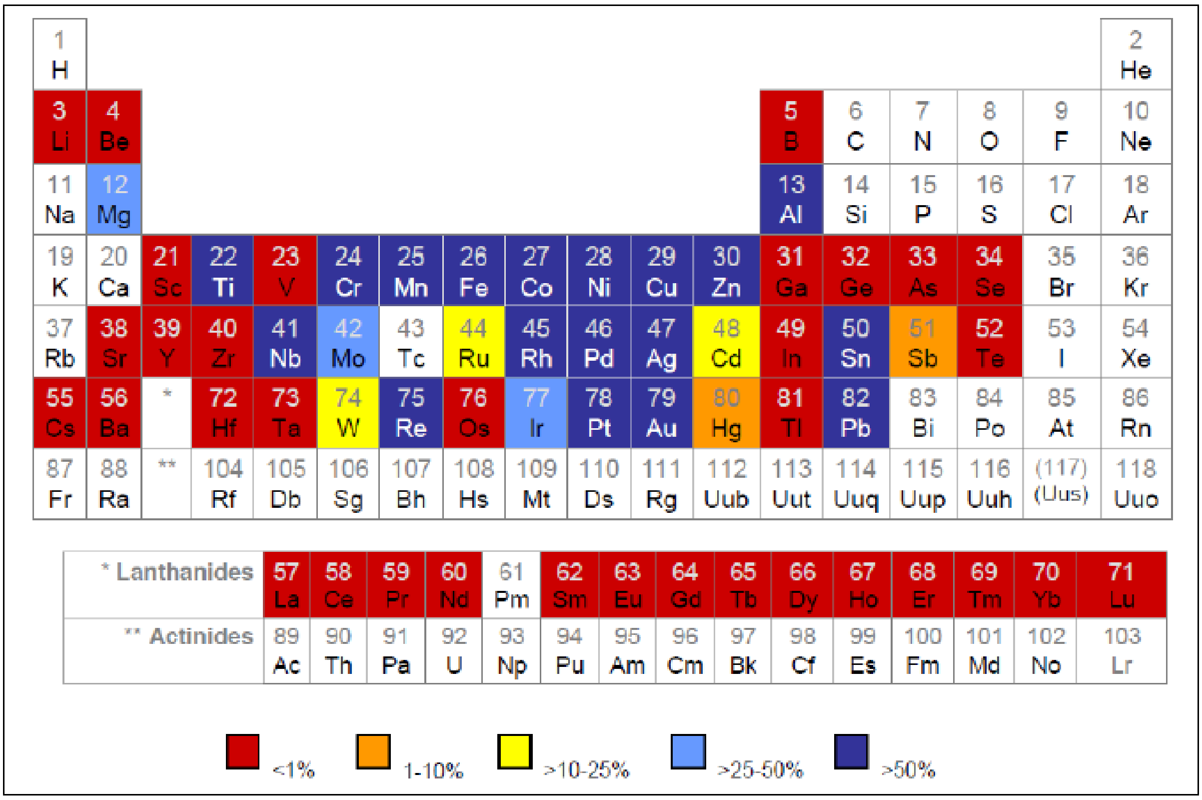

Figure 2 Recycling rates for critical materials (UNEP, 2011a)

This report aims to gather information, via a desk study, on what other countries in Europe and around the world are doing with regards to resource security and their strategic directions for the future. It also looks at what type of research is taking place at the university and research institution level. A number of studies and strategies have been reviewed and summarised in this report, in the hope of offering a useful format for the reader, making the most pertinent information from each study/strategy readily accessible.

There is a vast amount of information in the public domain, ranging from criticality assessments for countries and industries to very specific research on, for example, the issue of substitution. It was not the purpose of this study to review all of them, nor to seek to comment on the accuracy or conclusions of those referenced, but rather to gather readily available information and present a general view for consideration.

2. European Resource Strategy and Supporting Reports

Europe consumes 25-30% of all the metals produced globally, but it is only responsible for 3% of global metal production, and many important metals are not produced in Europe at all (Nurmi *et al.,* 2010). At the same time, intensity of European metal use is slowly decreasing, whereas recycling of metals is increasing and new material replacements are being found. However, export of recyclable materials, either legally or illegally, to developing countries is on the rise. As a result, the EU is becoming increasingly dependent on imports of certain raw materials. The European Commission recognised the need for a policy that would promote a shift to resource efficiency and sustainability to secure access to raw materials in the future.

2.1 The Raw Materials Initiative

In 2008, the European Commission launched the Raw Materials Initiative which aims to encourage transparency in raw materials trading worldwide, reduce waste and conserve resources, enhance expertise and develop new technology in the sector, and create a uniform mineral policy in Europe (COM, 2008).

To help address the risks discussed above and in Section 1, the Raw Materials Initiative proposes an integrated raw materials strategy for the EU based on three pillars.

Pillar 1: Secure access to raw materials by ensuring undistorted world market conditions:

- Through diplomacy with resource-rich countries such as China and resource-dependent countries such as the US and Japan for cooperation;
- Through international cooperation via fora such as G8, OECD etc. to raise awareness about the issues and create dialogue; and
- By making access to primary and secondary raw materials a priority for the EU trade and regulatory policy, to ensure that measures that distort open market trade such as restrictions of exports and dual pricing are eliminated.

Pillar 2: Foster sustainable supply of raw materials from European countries, by:

- Making sure the right framework conditions are in place to prevent delays in permitting that can inhibit new projects;
- Improving the European knowledge base on mineral deposits. The long term access to these deposits should be considered during land use planning;

- Better exchange of information between countries through networking between the national geological surveys;
- Promoting research projects with a focus on extraction and processing (7th Framework Programme) and also making funding available for projects; and
- Increasing the amount of skilled personnel by cooperating with universities and increasing public awareness of the importance of domestic materials.

Pillar 3: Reduce the EU's consumption of primary raw material, through:

- Improving resource efficiency such as by improving product design, for example through the Eco-Design Directive;
- Decreasing the amount of materials lost through illegal exporting in order to secure secondary raw materials. This will also require good relations with third countries to ensure the enforcement of Waste Shipment Regulations; and
- Increasing reuse and recycling through legislation, standards and labelling, financing, knowledge sharing etc.

2.2 The EU14 Critical Materials

The Raw Materials Initiative also outlines a way forward to raw material security, with one of the first steps being the identification of materials that are considered critical for the EU. This action was completed in June 2010 when the Ad-hoc Working Group on Defining Raw Materials published its report (European Commission, 2010).

When analysing material criticality, the report considered two types of risk: a 'supply risk' that took into account how concentrated production is, the political and economic stability of the producing countries, and the potential for substitution and recycling rate; and an 'environmental country risk' which assessed the risk that producing countries might strive to improve on their poor environmental performance and in so doing place regulations on the supply of raw materials to Europe. The report highlights that for the short term future (i.e. at least the next ten years) there is no actual risk of supplies of these materials physically running out.

A total of 41 materials were assessed for criticality and 14 materials (known as the EU14 critical materials) have been identified as critical. These are: antimony (Sb), beryllium (Be), fluorspar, graphite, germanium (Ge), indium (In), magnesium (Mg), rare earth elements (REEs), tungsten (W), cobalt (Co), tantalum (Ta), platinum group metals (PGMs), niobium (Nb) and gallium (Ga). The criticality of these materials stems mostly from the fact that a high share of their worldwide production comes from China, Russia, the Democratic Republic of Congo and Brazil and because, in many cases, the production concentration is compounded by low substitutability and low recycling rates. These critical materials are often derived as by-products or co-products, therefore whether they are mined at all depends on whether it is economically feasible to mine the main product (usually a base metal such as copper, aluminium, zinc) and whether there is demand for the base metal.

The report makes eight recommendations to help address the issue of supply security for these critical materials, and these can be broadly split into two categories.

Recommendations for follow-up and further support:

- Update the criticality assessment every five years and widen its scope;
- Improve data availability with regards to raw materials and disseminate the relative information, to encourage more research into the lifecycle assessments of these materials and to create working groups to further analyse the impacts of emerging technologies on demand; and
- Set up a sub-group of the EC Raw Material Supply Group to ensure that there will be a follow up to this report.

Recommendations to secure access to and material efficiency of critical materials:

- Promote sustainable exploration both within and outside the EU, promote research on mineral processing and extraction from various sources (including deep deposits, old mine dumps etc.), promote good governance, capacity-building and transparency when it comes to exploration projects in developing countries;
- Provide a level playing field in trade and investment through negotiating agreements, exchanging views and raising awareness;
- Take policy actions to ensure that recycling of raw materials and products containing them becomes more efficient through promoting collections, stopping illegal exports of end of life (EoL) products and promoting research on system optimisation and on tackling technical challenges;
- Encourage substitution by promoting research on substitutes of critical raw materials; and
- Improve material efficiency by using less material in production and minimising raw material losses.

2.3 EU Strategy on Raw Materials

The need to uphold the 3 pillars of the Raw Materials Initiative (RMI) and to follow up on the recommendations of the Ad-hoc committee's report were further reiterated in the Commission's Strategy on commodity markets and raw materials published in February 2011 (COM, 2011). This report describes the progress that the EU has made with regards to the Raw Materials Initiative, such as:

- Identifying the EU14 critical materials and defining a raw materials trade strategy;
- Providing funding for projects on mining and substitution of raw materials;
- Promoting resource efficiency through developing End of Waste criteria for specific waste streams; and
- Preventing illegal export of waste and proposing new ambitious targets for Waste Electrical and Electronic Equipment (WEEE) recycling.

The Strategy also reiterates the importance of the three pillars in further implementing the RMI actions. Additionally, it reiterates the Commission's desire to continue to monitor the situation to be able to identify priority actions and to update the list of critical raw materials at least every three years. The Commission's readiness to examine, together with Member States, the feasibility of establishing a stockpiling programme for critical materials is also mentioned.

2.4 Critical Materials in SET Technologies

Continuing its efforts to better understand the issues that Europe faces with regards to critical materials, the Commission's Joint Research Centre (JRC) published a report in October 2011, which investigated the potential bottlenecks associated with the use of metals in six energy technologies: nuclear, solar, wind, bio-energy, carbon capture and storage and electricity grids, identified as strategic in the Strategic Energy Technologies Plan (SET-Plan) (Moss *et al*., 2011). The SET-Plan oversees the steps that Europe must take to meet its targets for 2020, which are a 20% reduction in CO_2 emissions from 1990 levels, a 20% share of energy from renewable sources and a 20% reduction in the use of primary energy by improving energy efficiency.

To determine the metal demand, an optimistic scenario for deployment of these six SET-Plan technologies by 2020 and 2030 was developed and the annual demand for metals was compared to the global production volume of each metal in 2010. Therefore, this provided a criterion that is likely to overestimate the risks for potential shortfalls. Where the average annual metal demand from these technologies exceeded 1% of 2010 world supply, the metal requirement was considered significant. Particular emphasis was placed on analysing the combination of actual market dynamics when determining metal demand.

Table 2 summarises the expected contributions of each of the six technologies to the overall electricity mix for Europe in 2020 and 2030, shows the assumptions made during modelling to determine the metal demand and also shows the 14 metals for which there will be significant requirements from the six SET-Plan technologies in the year 2030 (no significant metal requirements were identified for 2020).

The JRC study then examined whether there is likely to be significant bottlenecks in the future for these 14 metals (with a view to the next 5 to 10 years) and concluded that five metals are facing significant bottleneck risks: dysprosium, neodymium, tellurium, gallium and indium (Table 3).

SET-Plan Technology	Expected contributions to electricity mix and assumptions	Significant Metal Requirements in 2030
Nuclear energy	Projection for 198 GW of nuclear capacity for 2020 and 297 GW for 2030.	hafnium 7.0%, indium 1.4%
Solar energy	PV is expected to contribute up to 12% of EU electricity demand by 2020. The PV technology mix is: 80% c-Si, 10% a-Si, 5% CdTe and 5% CIGS. Concentrated solar power (CSP) is expected to contribute around 3% by 2020 and at least 10% by 2030.	▪ Thin film technologies: tellurium 50.4%, indium 18% and gallium 3.9%. ▪ c-Si: tin 9.6% and Silver 4.7%. ▪ CIGS: selenium 0.8% but could be significant if CIGS ends up having a larger than expected share
Wind energy	Wind capacity of 230 GW for 2020 and 400 GW for 2030 (according to the European Wind Energy Association). Assumed technology mix: 15% permanent magnet in 2020 and 20% in 2030.	▪ Permanent magnet generators: dysprosium 4.0% and neodymium 3.8% ▪ Steel alloy: molybdenum 1.0%
Carbon Capture and Storage	Aim at 3,600 MW of power generation, via demonstration plants, to be CCS enabled by 2020	vanadium 1.3%, niobium 1.2%
Bio-energy	Aim of ensuring at least 14% bio-energy in the EU energy mix by 2020	There is some increased demand for ruthenium but since bio-fuels replace fossil fuels (which use the same catalyst) ruthenium is not

		included in the significance list
Electricity grids	The transmission and distribution of up to 35% of electricity from dispersed and concentrated renewable sources by 2020, and a completely decarbonised electricity production by 2050 (European Industrial Initiative)	No particularly stringent metal requirement

Table 2 Significant metal requirements for the 6 SET-Plan technologies in 2030 (Moss *et al.*, 2011)

Metal	**Market Factors**		**Political Factors**		**Overall Risk**
	Likelihood of rapid demand growth	**Limitations to expanding production capacity**	**Concentration of supply**	**Political risk**	
Dysprosium	High	High	High	High	High
Neodymium	High	Medium	High	High	
Tellurium	High	High	Low	Medium	
Gallium	High	Medium	Medium	Medium	
Indium	Medium	High	Medium	Medium	

Table 3 The five high bottleneck risk metals and their contributing factors (Moss *et al.*, 2011)

In the case of the rare earths neodymium (Nd) and dysprosium (Dy) the risks are related to the commercial and technical challenges in bringing new mines to the market. This is particularly the case for dysprosium which is underrepresented in most rare earth ores relative to supply. There are also high political risks to supply since 95% of rare earth production takes place in China. In the case of tellurium (Te), indium (In) and gallium (Ga) the risks mainly arise from their by-product nature. Even with high prices, the small market size for these three speciality metals creates a very small incentive for refiners of zinc, copper and aluminium ores to invest in optimal by-product recovery.

The report goes on to discuss possible mitigation strategies for reducing the risk of bottlenecks in the future. These are described in detail in the report. In general, substitutions for dysprosium and neodymium at the system level are more viable options than substitution in products. Also, with the exception of replacing indium in indium-tin oxides (used mainly in flat panel displays), very little effort appears to be undertaken to replace gallium, indium and tellurium with other elements.

Finally, the report contains a very brief discussion of the environmental impacts of these metals. Although data to determine their impacts are incomplete, the report concludes that since Te, Ga and In are co-products their environmental impacts are likely to be low. The environmental impact attributable to the production of neodymium and dysprosium would probably be higher (since they are a main mining product) but research done on electric vehicles (Oakdene Hollins, 2010) shows that the benefits are higher than the alternatives (i.e. combustion engines).

3. National Strategies and Supporting Studies

Various nations around the world have formulated strategies on securing raw materials supplies for their economies. The action points described in these strategies depend on the situation in each of the countries. In general, while resource and technology rich nations outline actions to maintain and expand their exploration and production industries, resource-poor nations plan to concentrate their efforts on diplomacy and resource efficiency to maintain supplies of critical raw materials. This chapter describes the materials strategies of Germany, France, Finland and the Netherlands (the four EU nations that have formulated strategies so far), the US raw material strategy, Canada's position with regards to raw materials, and to illustrate the priorities of Asian economies, the Japanese, Korean and Taiwanese strategies. Where other documentation on resource security was available for each of these countries, this is also summarised here.

In addition, many countries have developed resource efficiency strategies that touch on resource security issues. These are summarised in Section 5.1.

3.1 Germany

Germany is one of the few European nations that have developed their own strategy with regards to raw materials (Federal Ministry of Economics and Technology, 2010). This mainly refers to non-energy sources. The document makes brief mention of the EU 14 critical materials and of phosphorus. However, the German Ministry of Economics and Technology also commissioned a more specific report, examining how emerging technologies will affect the German demand for raw materials and the raw materials on which these technologies are particularly dependent (Angerer *et al.*, 2009). This section summarises both of these reports. Additionally, Section 3.1.1 summarises some pertinent information, reported in the press, on German action to secure raw materials.

3.1.1 German Strategy on Raw Materials

The German government emphasises that it is the responsibility of German industries to ensure that they have the long-term supplies of the key materials they need. It is clarified at the beginning of the strategy that the German government does not intend to become active in exploration, extraction and stockpiling of materials. Rather, the German raw materials strategy aims to describe the financial and political support that will be made available to German companies with regards to dealing with bottlenecks in supply (Federal Ministry of Economics and Technology, 2010).

The German government developed its strategy after the introduction of export tariffs in countries producing certain raw materials. The main aims of the strategy are:

- To promote domestic exploration, extraction and reprocessing of raw materials in order to develop an integrated industrial structure with a great depth of manufacturing that will be less prone to market disruptions;
- To promote foreign investment in mining projects;
- To focus on research and development (R&D) for resource efficiency and recycling;
- To increase education and information diffusion; and
- To establish partnerships with various producer countries.

In greater detail, the actions that the German government aims to take with regards to raw materials can be divided into four main groups.

A. Diversification of supply sources of materials

This encompasses mostly financial incentives to promote exploration, domestic extraction and investment. The German government recognises that German companies wishing to invest in raw materials projects abroad, and particularly in developing and emerging economies, face significant political and commercial risks. Therefore, the government will make available investment guarantees and guarantees for untied financial loans. Furthermore, export guarantees will be provided to insure those companies that supply equipment to new foreign developments against the risk of non-payment.

Exploration to identify new sources of raw materials abroad can be prohibitively expensive, therefore the German government states that it will look into ways to reallocate some budget (in the form of loans) to cover the risks of German companies involved in the field, while placing particular emphasis on projects exploring for the EU 14 materials. Similarly, the German government is keen to promote domestic extraction of raw materials, as long as land use issues are respected. This is also supported by the German Federal Institute of Geosciences and Natural Resources, which undertakes geological surveys in oceans and frontier areas as part of research projects to promote diversification of supply.

B. Material efficiency, recovery and recycling

According to the strategy, Germany has a very good recycling track record and for certain materials it has some of the highest recycling rates in Europe. Examples include aluminium (35% recycled), lead (59%), steel (90%), cobalt (20-25%) and molybdenum (10%). The German government plans to continue to improve the recycling rates of reusable materials through its Closed Substance Cycle and Waste Management Act.

However, it is recognised that recycling alone will not be able to ensure a sustained supply of raw materials. Therefore, the German strategy plans to improve the material efficiency of products by making funding available to projects working on resource-efficient technologies, substitution and recycling. Small and medium enterprises (SMEs) in particular will be targeted to increase their awareness of the need and benefits of materials efficiency. The Materials Innovations for Industry and Society framework programme of the German Ministry for Education and Research is particularly involved in R&D projects dealing with the issues of substitution and resource intensity in key applications. For example, one of the key projects of the programme, funded together with the Environment Ministry, investigates the extraction of phosphate from secondary sources.

C. Information and education

The German government recognises that there is a real need to improve the diffusion of information with regards to raw materials. This is why, in October 2010, the German Mineral Resources Agency was established, whose aims are to:

- Establish an information system for raw materials;
- Provide tailored advice to businesses, with a special focus on SMEs, on reducing supply risks, diversifying supplies and applying more efficient processes when extracting and processing materials;
- Provide expert support and advice to the government for setting up and carrying out exploration and extraction assistance programmes;
- Help with R&D projects that study the potential for raw materials and develop instruments and methods for mining; and
- Co-operate with countries rich in raw materials.

In addition to making information more available for businesses the German government aims to invest in developing expert talent in the areas of exploration and extraction of raw materials by strengthening the faculties at German universities that deal in geosciences, raw materials and mining. The importance of educating foreign students that attend German universities is highlighted, as this ‘opens their mind to German interests’. Within the focus on education and research, Germany is also working on establishing a Research Institute for Resource Technology.

D. Provide political support to German companies

The strategy clarifies that the German government will not influence price negotiations for materials, but that it nonetheless intends to pay close attention to market developments and ensure that these are transparent and in agreement with international competition law. The role of the government with regards to raw materials will be one of support, through political and financial means, to ensure security of supply.

Various institutions in Germany provide political support to German firms to ensure supply security for raw materials but it is up to the individual companies to develop specific projects, identify needs for support and communicate this to the government. Support usually involves advocating the issuing of overseas exploration and extraction licenses for German firms. In order to help with this task, the Inter-ministerial Committee on Raw Materials was set up in 2007.

The German strategy on raw materials also states that it is the role of government to form agreements with countries rich in resources. In October 2011 the German Chancellor Angela Merkel signed an intergovernmental agreement for a resources, industry and technology partnership with the Mongolian Prime Minister Sukhbaataryn Batbold, to secure German access to Mongolia's REEs and coal. In exchange, Germany will be providing the machines to extract resources. It is reported that a similar alliance is being sought with the government of Kazakhstan (Kosich, 2011). The German government is also supporting a consortium of twelve major German conglomerates, called the Alliance for Raw Material Security, to be founded in early 2012, which will create a resource company that will ensure that the German industry has independent access to critical materials. This support comes in the form of political backing as the twelve companies intend to cover the financial costs themselves (Stratman, 2011).

According to another article in Financial Times Deutschland on 18 November 2011, the Federal Ministry of Economics plans to establish an Exploration Support Programme, to give financial support to companies that explore and exploit raw material reserves abroad. The support will be given in the form of conditionally repayable subsidies, meaning that companies will only have to pay back the loans if their explorations find reserves that can be exploited profitably (Financial Times Deutschland, 2011).

3.1.2 Raw Materials for German Energy Technologies

A study commissioned by the German Federal Ministry of Economics and Technology and undertaken by IZT and Fraunhofer in 2009 examined, via an analysis of 32 emerging technologies and 22 raw materials, how emerging technologies will affect the German demand for raw materials and on which raw materials these technologies are particularly dependent on (Angerer *et al.*, 2009).

The approach taken by the study was to compare the demand for the selected raw materials arising from the chosen technologies in 2006 to the predicted demand in 2030. The results, which are summarised in Table 4, show that for seven of these materials demand will be greater in 2030 than the 2009 supply. For example, demand for gallium in 2030, arising from these technologies alone, is projected to be

6.09 times greater than the total amount of gallium produced at the time of the investigation.

The analysis showed that while the main driver of demand for copper, iron, steel and chromium seems to be world economic growth, the main demand driver for speciality metals such as gallium, neodymium, indium, germanium and scandium is more likely to be technological innovation. For the demand for platinum group metals, tantalum, silver, titanium and cobalt both drivers seem to be important.

The study also investigated whether supply of raw materials can be secured for the future given that demand is expected to rise. Given the time it takes for technology developments to move out of the laboratory and into the market, and the lead times for mining operations, the authors suggest that raw material providers will have enough time to adapt to market demands for their products assuming that there is timely communication and information exchange between mining companies and industries using the raw materials.

The study emphasises the fact that the raw materials processing sector is a global network susceptible to a number of interlinked influences and this makes it particularly vulnerable to disruptions. This is further compounded by the fact that there are still numerous things that we do not understand about these raw materials, such as their substitutability (for a number of specific metal applications there are no substitutes at the moment), efficiency potentials and unexploited recycling potentials to name a few. Added to these issues is the fact that the market for these materials is susceptible to speculative action which could lead to very high prices. According to the authors of the report, all these issues merit further investigation, particularly for those industries that make up a large proportion of the German economy (e.g. automotive).

Another recommendation coming out of the report is that, since secondary raw materials are the only domestic source of metal raw materials in Germany, recycling technologies able to separate high quality secondary raw materials from composite materials and products are necessary.

Like the authors of other reports on critical raw materials, the authors of this report were faced with difficulties when it came to finding the necessary information and data. Therefore, they suggest that a transnational institution should be created that would not only be responsible for gathering and sharing information about these materials but would also act as a coordinator for dialogue between the mining industry and the industries using the raw materials, as this could help balance supply and demand and calm the market.

Raw Material	2006	2030	Emerging Technologies (selected)
Gallium	0.28	6.09	Thin layer photovoltaics, IC, WLED
Neodymium	0.55	3.82	Permanent magnets, laser technology
Indium	0.40	3.29	Displays, thin layer photovoltaics
Germanium	0.31	2.44	Fibre optic cable, IR optical technologies
Scandium	Low	2.28	SOFC, aluminium alloying element
Platinum	Low	1.56	Fuel cells, catalysts
Tantalum	0.39	1.01	Micro capacitors, medical technology
Silver	0.26	0.78	RFID, lead-free soft solder
Tin	0.62	0.77	Lead-free soft solder, transparent electrodes
Cobalt	0.19	0.40	Lithium-ion batteries, synthetic fuels
Palladium	0.10	0.34	Catalysts, seawater desalination
Titanium	0.08	0.29	Seawater desalination, implants
Copper	0.09	0.24	Efficient electric motors, RFID
Selenium	low	0.11	Thin layer photovoltaics, alloying element
Niobium	0.01	0.03	Micro capacitors, ferroalloys
Ruthenium	0	0.03	Dye-sensitized solar cells, Ti-alloying element
Yttrium	low	0.01	Super conduction, laser technology
Antimony	low	low	ATO, micro capacitors

Chromium	low	low	Seawater desalination, marine technologies

Table 4 Predicted raw materials demand for emerging technologies in Germany (as a factor of the material production in 2009) (Angerer *et al.*, 2009)

3.1.3 Raw Materials for the German Economy

A more recent study, carried out by the Institute for Future Studies and Technology Assessment (IZT) and adelphi for KfW Bankengruppe, analysed 52 materials to determine the vulnerability of the German economy to their supply disruption. It identified 13 raw materials as critical (indium, tungsten, rare earths, gallium, palladium, silver, tin, niobium, chrome and bismuth) and very critical (germanium rhenium and antimony) (KfW, 2011). It was not possible to access the whole report, but the press release refers to the high supply risk associated with these materials as a result of their concentration in a few countries and the market risks resulting from the low ratio of reserves to production as the main reasons for their criticality. Additionally, the small-scale use of these materials and the wide geographic distribution of their use result in difficulties associated with their recycling.

3.2 France

Although France has developed its own materials strategy, it was not possible to obtain an English version of this document and summarise it here. Nonetheless, some details are available through France's country profile in the European Environment Agency's 'Resource Efficiency in Europe' report (EEA, 2011). France's Strategic Metals Plan stresses the need to identify the areas which make France vulnerable to resource scarcity and determine how to remedy the situation. The strategy also states the government's aspiration to extend geological knowledge with targeted exploration campaigns for strategic metals. The promotion of sustainable exploitation, development of new tools for use in exploration and the investigation of ways to make the extraction and the transformation of strategic metals easier are also aims of the strategy. Furthermore, it aims to look at the recycling policy for strategic metals and strengthen governmental action by appointing a senior civil servant for strategic metals.

In order to meet the aims of France's Strategic Metals Plan, in January 2011, the French Ministry of Industry set up the Committee for Strategic Metals ("Comité des Métaux Stratégiques", or COMES). The Committee, which is made up of representatives from research institutes and industry from across the metals sector, has set up for working groups to consider the following themes (British Embassy France, Pers. Comm.):

1. Understand industrial needs with respect to critical metals.
2. Identify the most critical resources and update the mining inventory with a view to starting new prospecting, in both land and sea.
3. Accelerate implementation of recycling projects. Increase R&D efforts, in particular on substitution.
4. Develop necessary European and international co-operations.

Online articles also add to the picture of France’s materials strategy. Continental France today has no significant metal resources but French Guyana has important gold reserves and New Caledonia has a proportion of world reserves of nickel. Abundant polymetallic nodule deposits, containing nickel, manganese, copper and cobalt, have also been identified in the French Exclusive Economic Zone around Clipperton Island. However, it is not at this stage economically feasible to extract these resources (Dozolme, n.d.). Therefore, like most European countries, France is dependent on imports for most of its metals.

In March 2011, French senator Blanc issued a French parliamentary report that identified a number of metals as critical for France based on the key applications that they are used in. These appear in Table 5. In order to secure supplies of these critical materials in the future the report proposes among other things to:

- Foster partnership strategies with the biggest producers (China, Russia and Brazil);
- Perform a thorough audit and inventory of French mining resources and reserves;
- Simplify the French mining code;
- Massively increase public involvement and investment in the metals recycling industry; and
- Sponsor the pending developments that could make the Clipperton Island’s polymetallic nodules extraction possible and profitable.

Critical Metal	Use(s)
Indium and Rare Earth Elements	LCD flat screens
Rare Earth Elements	Wind turbine permanent magnets, hybrid car engines
Gallium	White LED and solar panels
Selenium	Solar panels
Germanium	Solar panels, transistors, portable Wi-Fi devices
Lithium and Cobalt	Batteries
Tantalum, Niobium and Rhenium	Super-alloys manufacturing

Table 5 Critical raw materials for the French economy (Dozolme, n.d.)

In September 2011, The Bureau de Recherches Geologiques et Minieres (BRGM), which is the French public institution in earth science applications, and the European Company for Strategic Intelligence (CEIS) signed an agreement with the Kazakh national uranium miner, Kazatomprom, to help it develop Kazakhstan's rare earth metal deposits, through exploration, development of production technology and conduction of feasibility studies for future mining operations (Silk Road Intelligencer, 2011).

Progress has also been made in France in the area of recycling, particularly for rare earth elements. Earlier this year, Rhodia, a French chemicals company, announced plans to recycle the rare earths neodymium, praseodymium, dysprosium and terbium found in permanent magnets used in wind turbines, electric vehicles and hard discs, and use these materials to produce parts for other products, such as rechargeable batteries (Waste Management World, 2011). This plant will be operational in France in the first quarter of 2012. The company also announced another scheme, which is expected to be operational at the end of the year, to recycle rare earths from NiMH rechargeable batteries.

3.3 Finland

Finland makes for a particular case when it comes to raw material strategies in Europe, because unlike the majority of European countries, Finland has a strong domestic mineral industry (Nurmi *et al.*, 2010). In fact, as Table 6 shows, Finland has mining projects, mining production or deposits for a large number of materials considered critical, very important and important by the EU. Therefore, Finland's policy places a focus on the Finnish mineral sector which covers: mining of metallic ores and industrial minerals, industries that extract and process aggregates and natural stones, industries that produce and supply machinery, equipment, technology and services for mining operations, and various institutions including research organisations and agencies, universities and technical and trade schools.

The Finnish mining industry is mostly concentrated in the eastern and northern parts of the country. Due to the recent demand for raw materials there has been further interest in, and growth of, the sector leading to the opening of a number of new mines. These new mines have led to the diversification of the types of metals extracted in Finland and therefore to a slow decrease in the amounts of raw materials imported for the metals refining sector. Most of the raw materials that are extracted in Finland are also refined in Finland and for the most part used domestically. Only a small amount of domestically produced raw materials are exported, although Finland is a great exporter of mining technology (as is Sweden). In fact, it is estimated that when an underground mine opens anywhere in the world, 70-90% of the required technology comes from either Finland or Sweden.

Finland’s strategy tries to anticipate international and domestic trends in the minerals sector over the next few decades and makes the following recommendations on the formulation of a minerals policy and the further development of the minerals sector in Finland:

1. The significance, growth potential and risks associated with the minerals sector should be recognised and the government should act as a facilitator to the sector.

2. Establish mineral policies in cooperation with Sweden and other EU countries to promote the Raw Materials Initiative.

   The strategy sees Finland taking a leading role in developing regulatory regimes and administrative policies and institutions in the minerals sector in developing countries. Such a role would not only increase Finland’s international influence and support in promoting awareness of the impacts and responsibilities associated with natural resources, but would also create export opportunities for Finnish industry.

3. Increase Finnish ownership in Finland’s mineral sector and improve the sector's

financing opportunities.

The majority of exploration and mining companies in Finland are small or medium sized mining companies mostly owned by foreign investments. Increasing Finnish ownership will be achieved through public support for infrastructure investment and lending and loan guarantees for mining investments.

4. Investigate the potential of using tax incentives to promote exploration of natural resources and for efficient use of resources.

   As Table 6 shows, Finnish bedrock contains significant known deposits of critical materials and has considerable potential for discovery of new resources. However, exploration is notoriously risky and expensive, therefore very few companies can take part in such activities. Furthermore, it takes 10-15 years to move from exploration to opening a new mine and only a few of every thousand of explorations evaluated will lead to discovery of an economically viable deposit. However, since it is anticipated that Finland could have deposits of critical minerals it is important for the government to help support exploration projects.

5. Enhance the compilations, interpretation and distribution of geo-scientific and environmental data.

6. Reduce permit processing times and refine permitting procedures.

7. The supply and sustainable utilisation of mineral resources should be regarded as integral to land use planning.

8. Establish mechanisms that promote cooperation between residents, companies and regulatory authorities to ensure sustainable well-being of individuals and communities.

   This also relates to point 7 above. In general, communities respond positively to new mines opening in the area as this creates jobs for the community. It is reported that for every one job created directly from a mining activity a further 3 or 4 are created indirectly. Additionally, jobs created by the mining industry are considered to be long-term employment.

9. Improve the material and energy efficiency of machinery, equipment and processing technologies used in the mineral sector. Create incentives for the recycling and reuse of stockpiled waste, tailings and mineral products. Encourage the presentation of an annual award for excellence in resource efficiency.

10. Promote green economy businesses through cooperation between SMEs and research institutes by bringing together experts from the entire mineral sector.

11. Establish a research programme under the Finnish Funding Agency for Technology and Innovation (Tekes) aimed at developing innovative solutions, products and services throughout the mineral utilisation chain.

12. Invest in education.

    The Finnish minerals sector is facing a shortage of experts. Therefore, education about the sector is of paramount importance. This would be done by stressing the importance of minerals and metals in everyday life at all educational levels, reinforcing teaching resources at universities, providing research funding for leading research at the international level in selected fields, and providing specialised courses at universities according to future needs.

CRITICAL			ECONOMICALLY VERY IMPORTANT			ECONOMICALLY IMPORTANT		
Metal/Mineral	**Mining**	**Potential**	**Metal/Mineral**	**Mining**	**Potential**	**Metal/Mineral**	**Mining**	**Potential**
Cobalt	Production	Good	**Nickel, Zinc, Chromium**	Production	Good	**Copper, Feldspar, Limestone, Quartz, Talc**	Production	Good
Niobium, PGMs	Projects	Good	**Vanadium**	Projects	Good	**Lithium, Titanium**	Projects	Good
REEs	Deposits	Good	**Iron, Manganese**	Projects	Moderate	**Silver**	Projects	Moderate
Antimony, Graphite, Tantalum, Tungsten	Deposits	Moderate	**Tellurium**	Deposits	Good	**Clay Minerals**	Deposits	Moderate
Beryllium, Indium	No deposits	Moderate	**Molybdenum**	Deposits	Moderate	**Barite**	No deposits	Moderate

Fluorspar, Gallium, Germanium, Magnesium	No deposits	Low	**Magnesite**	No deposits	Moderate	**Bentonite, Boron, Diatomite, Gypsum, Perlite**	No deposits	Low
			Aluminium, Rhenium	No deposits	Low			

Table 6 Mining production and deposit discovery potential for raw materials in Finland (Nurmi *et al.,* 2010)

3.4 The Netherlands

The Dutch strategy on raw materials offers only an initial analysis of the materials that could be important for the Dutch economy, and takes a general approach to outlining the issues surrounding raw material security. This is supplemented by two reports, one from 2010 by Statistics Netherlands, which discuses the preliminary results of a criticality assessment for the Dutch economy, and a later one published by the Netherlands Environmental Assessment Agency, which examines which future resource scarcities, if any, should concern the European Union and the Netherlands and what policy strategies are available to them to deal with these scarcities. All three reports are summarised below.

3.4.1 Dutch Raw Materials Strategy

The Dutch government's policy on raw materials covers both biotic and non-biotic raw materials (Dutch Ministry of Foreign Affairs, n.d.). However, since the Dutch government had already assessed its needs with regards to biotic raw materials through its biodiversity policy programme (2008) and its sustainable trade initiative, there is a slight focus on non-biotic raw materials in this report.

While, according to the strategy, it is the responsibility of trade and industry to secure the main raw materials they need, the Dutch government should offer its support by means of coordination, facilitation, encouragement and creation of frameworks. The Dutch strategy is heavily influenced by the fact that the Netherlands is a major transit route for Europe and therefore the Dutch economy relies heavily on logistics, imports and exports. Therefore, one of the key points in the Dutch strategy is to help and support Europe at promoting an open trading system for raw materials. The Dutch belief is that the issue of raw materials is a global one and one that is very difficult for individual nations to try to address on their own. Therefore the government is a firm believer in the principle of 'European where possible, national where necessary and where it offers opportunities'.

An initial analysis to identify key raw materials for the Netherlands started by looking at the 41 materials examined by the EU, in addition to phosphate, tin and gold, and resulted in the list appearing in Table 7. However, no national materials priorities have been set and the Dutch government is planning to carry out additional analysis that will consider business and top economic sectors.

Top economic sectors dependent on raw materials	
Sector	**Examples of related products and raw materials**
Agri-Food	Phosphate for fertilisers, soya for cattle feed, palm oil, cocoa, coffee, spices, fish (meal)
Horticulture and seed stock	Peat as a substrate for plant breeding and cultivation
High-tech materials and systems	Germanium in optic cables and optic infrared technologies; cerium in computers; antimony, niobium and tantalum in micro-condensers; iron ore, coke, injection coal, tin and zinc ores for steel; bauxite/alumina for aluminium; silver, gold and copper for electronic equipment; tungsten, niobium, vanadium, nickel, manganese and chrome for special steels
Energy	Neodymium, dysprosium and samarium in permanent magnets; indium, gallium, selenium and tellurium in solar cells; platinum in fuel cells; europium, yttrium, gallium and indium in LED lighting; lithium, cobalt and rare earths in battery technology; biomass for energy generation
Logistics	Lithium and neodymium in electric cars; cobalt and samarium in high-speed trains; scandium alloys in light-weight aeroplane frames; magnesium for metal alloys in cars; platinum, palladium and rhodium in catalytic converters
Creative industry	Niobium, antimony and tantalum in computer chips; rare earths such as yttrium, europium, terbium and indium in LCD technology
Life-sciences	Tantalum in medical technology
Chemical industry	Platinum and palladium in catalysts; cobalt in synthetic fuel; rare earths as catalysts
Water	Palladium for desalination; timber for piling, scaffolding and mooring bollards

Table 7 An initial analysis of the key raw materials for the Dutch economy (Dutch Ministry of Foreign Affairs, n.d.)

Another study was carried out to assess the extent of dependence of the Dutch economy on neodymium, indium and copper, looking at sectors that produce or process goods containing these metals. Sectors using indium accounted for nearly a billion Euros of added value in 2009 and also employed more than 22 thousand people (0.3% of the Dutch total). Neodymium using sectors accounted for 250 million Euros and 7300 employees (0.1% of the Dutch total), whereas copper using sectors accounted for 2.9 billion Euros (0.6% of Dutch GNP) and 70.4 thousand jobs (0.9% of the Dutch total).

To further analyse the issue of raw materials security, the Dutch government appointed a Special Representative on Natural Resources whose task is to prepare an international policy on long-term sustainable supply of raw materials for the Dutch economy. It is expected that this will entail networking with industry, research institutions, government officials and other organisations as well as building and extending bilateral relations with producing countries.

The policy aims of the Dutch government with regards to raw materials focus around three agendas:

1. Securing availability and improving sustainability of raw materials by seeking new supplies, closing cycles (re-use, recycling) and seeking alternatives to phosphates as a finite resource.

   One of the key issues for achieving this agenda is to optimise the use of raw materials within the Netherlands, and the EU in general, and to reduce dependency for materials from abroad. According to the strategy this will be achieved by removing any rules and regulations that pose unnecessary barriers for industry. For example, by setting up new initiatives for finding sustainable solutions to raw materials shortages and by carrying out feasibility studies into cooperation with Japan in the field of recycling and substitution of raw materials and into cooperation with Australia and China to reduce ecological stress due to production of raw materials. The Dutch government also aims to create a Phosphate Action Plan to help find solutions to the shortage of phosphates. With regards to biotic resources, the government is planning to work with stakeholders to facilitate peat certification and to find alternatives to peat.

   Promoting international stability and increasing the transparency of contracts and financial flows is another key step in securing the availability and sustainability of raw materials. What the Dutch Strategy suggests involves the promotion of certification initiatives and of the Extractive Industries Transparency Initiative (EITI). It not only recommends to set up a similar initiative in the Netherlands but also to lobby international financial institutions to give priority support to countries that uphold EITI rules. In addition, it advocates that assistance and expertise in contract negotiations should be provided to producing countries if they uphold EITI rules. In turn, help should be provided to developing countries that have successfully implemented EITI to offer assistance and advice to other countries.

At the European level, the Netherlands hopes to obtain one of the ten pilot demonstration plants made available under the Raw Materials Initiative and to share Dutch experience, best practice and expertise with other EU members. Finally, they would use EU frameworks to push initiatives that are important to the Dutch economy and contribute to initiatives to increase transparency in trading.

2. Restrict national demand for raw materials and make it more sustainable.

   The Dutch government aims to lead by example when it comes to raw materials, by introducing criteria to improve the sustainability and restrict the use of raw materials in its tendering process for large construction contracts, by paying more attention to raw materials when it comes to government purchasing and by improving its own management operations. This includes making chain agreements about product design, better use of waste flows, the purchase of services instead of products and the recovery of phosphates from waste water.

   Additionally, when setting up its material priorities, the government will invite the top economic sectors to identify which materials they consider to be 'at risk'. They will also encourage the development of alternatives through substitution, reducing consumption and reuse of materials through the Small Business Innovation Research Programme.

   In the EU context, the Dutch government aims to investigate opportunities to promote sustainable trade and production of biotic materials other than timber and overall discourage the consumption of raw materials produced unsustainably.

3. Improve the efficiency and sustainability of raw materials consumption within the Dutch economy by transforming raw materials chains, promoting market operation aimed at sustainable security of raw materials and more intelligent design of processes and products.

   This aim is to be achieved by closely cooperating with the EU and with the Dutch industry. At the EU level the Dutch government aims to help promote and further implement the Sustainable Trade Initiative and to make an active contribution to the review of the eco-design directives. At a national level, the government aims to encourage industry to take up action plans that champion sustainability and to create a concrete Dutch Sustainability Agenda. To further improve efficiency and sustainability, the government will support producing countries in meeting sustainability and quality standards during raw materials production.

The Dutch government has an overall positive outlook on the issue of materials security and believes that it can offer opportunities to the Dutch economy in the form of promoting the Netherlands' unique expertise in (deep sea) exploration and sustainable extraction of non-biotic materials as this becomes more economically desirable. It also envisions that as alternatives to extraction, such as recycling and raw materials innovation, become more favourable due to price rises, the Dutch recycling industry could benefit. Therefore, the government aims to promote close-loop and high quality recycling of raw materials.

3.4.2 Critical Materials in the Dutch Economy

This report was commissioned by the Dutch Ministry of Economic Affairs, Agriculture and Innovation and its objective was to assess the dependency of the Dutch economy on 44 critical materials (the 41 materials listed by the EU working group as well as phosphorus, uranium and gold). The work was carried out by Statistics Netherlands (CBS) together with the Netherlands Organisation for Applied Scientific Research (TSO) and the Institute of Environmental Sciences Leiden (CML) (Statistics Netherlands, 2010).

The methodology used in this study was experimental and somewhat unusual, as it used the monetary value of the materials used in each industry, and the product use to identify which ones showed the greatest occurrence of the critical materials (figures from 2007). Therefore, it is not a criticality assessment as such, since all the materials were considered to be critical. The following industries showed a large occurrence of critical materials: Manufacture of basic metals and fabricated metal products, Manufacture of machinery and equipment not elsewhere classified (nec) and Manufacture of transport equipment. The study also identified the following product groups with a large occurrence of critical materials: Glass and construction materials, Basic metals, Metal products, Machinery and equipment nec, Office machinery and computers, Electrical machinery nec, Medical precision and optical instruments, Motor vehicles, Other transport equipment and Electricity and gas.

The process resulted in a 'Critical materials by product group' indicator which estimates the percentage of intermediate consumption of each product group that is critical, and in a 'Critical materials by industry' indicator which shows which industries produce the product groups with occurrence of critical materials.

3.4.3 Resource Scarcities and Policies in the EU and the Netherlands

This report, published in 2011 by the PBL (Netherlands Environmental Assessment Agency), examined which future resource scarcities, if any, should concern the European Union and the Netherlands and what policy strategies are available to them to deal with these scarcities (PBL, 2011). This study took a broader view and looked at energy, food, water and mineral resources, considering in particular the EU14 critical materials, base metals and phosphorus.

The study notes that there are important interactions and trade-offs between these four main resource groups, and so an integrated framework of policies is necessary that takes these into account. At the moment, such a framework does not exist in the EU or the Netherlands. Therefore, the study highlights the need for additional information collection on individual resources, as well as the need to closely monitor resource flows, through promotion of transparency at an international level. Furthermore, it calls for monitoring of the effects of resource flows, for example interactions with climate change and biodiversity loss.

The physical, economic and political dimensions related to future scarcities for these resources were examined, together with their effects on climate change and biodiversity. The study found that overall, concerns for resource scarcity have moved from a physical dimension to an economic and political dimension. This is mainly because there are no major concerns about physical resource scarcity as reserves for most minerals will last for over a century at current production rates. However, demand for certain minerals is likely to increase in the future leading to their extraction from deposits with lower concentrations, which could cause environmental impacts. Additionally, mineral reserves for specific materials might not be sufficient to meet the expected future demand.

According to the study, the main resource scarcity concerns for the EU and the Netherlands are with regards to energy and mineral resources, where import dependency of the EU is high and likely to increase in the future. The report suggests that the EU and the Netherlands should put in place policies that will prevent a situation of fierce resource nationalism, since if such a situation were to occur, the EU and the Netherlands would be poorly equipped to deal with it. Table 8 summarises some key policy options that are available to both the EU and the Netherlands to help them deal with mineral scarcities.

Scarcity Dimension	Key Policy Options
Physical *Expand the resource base and reduce demand growth fundamentals*	– Build strategic reserves for critical minerals, e.g. rare earths, as a buffer against supply disruptions (long-term) – Open/reopen mines, invest in exploration (not an option for the Netherlands, but may be an option for Europe) – Bilateral agreements with supplying parties, establish strategic partnerships with important producer countries – Improve recycling – Improve resource efficiency – Reduce resource intensity: encourage substitutes, focus R&D on substituting elements
Economic *Improve functioning of markets*	– Options under ‘physical dimension’ – Anti-trust legislation
Political *Prevent politically motivated supply disruptions and market distortions*	– Options under ‘physical dimension’ and ‘economic dimension’ – Invest in global governance (liberalise world markets and collaborative governance, stabilise tight markets, prevent conflicts) – Develop bilateral cooperation in the field of raw materials and work together on issues such as governance, infrastructure, investment and geological knowledge and skills – Invest in development cooperation (development aid, transparency, good governance) – Consider shaping a new EU-wide policy on foreign investment agreements to ‘better protect EU investments in raw materials abroad’ – Consider the merits of pursuing dispute settlement initiatives at WTO level ‘to include in such initiatives more raw materials important for EU industry’ – Proactive acquisition

Table 8 Policy options available to the Netherlands and the EU to deal with resource scarcity (PBL, 2011)

3.5 USA

In December 2010, The U.S. Department of Energy (DOE) published the 'Critical Materials Strategy' for the U.S. and in 2011 it published an updated version. Both of these reports are summarised below. A table containing information from both of these reports is also presented below (Table 9), as it provides a very useful summary of what other nations around the world are doing with regards to critical materials. It clearly demonstrates how each country's policies depend on whether they have direct access to these resources or not. For example, whilst China aims to protect its resources, the EU and the Netherlands are promoting recycling and recovery and controlled austerity to minimise their dependency on imports, and Japan and South Korea are trying to secure more resources.

3.5.1 Critical Materials Strategy 2010

Although this is not an all-inclusive strategy (it only considers materials that are critical for the energy sector, specifically wind turbines, electric vehicles, photovoltaic cells and fluorescent lighting) it does take a holistic approach at determining criticality (U.S. DOE, 2010). It starts off with gathering and presenting information on the materials used in each of the four technologies and continues by presenting production and reserve information for each of the materials, including how they are processed. The report also presents historical supply, demand and price data for the materials and carries out scenario testing to assess demand and supply in the short (2015) and medium term (2025). Finally, taking all the previous information into account, the strategy concludes with a criticality assessment.

The following materials were analysed in the 2010 DOE:

- in electric vehicle batteries: lanthanum, cerium, praseodymium, neodymium, cobalt, lithium;
- in magnets for electric vehicles and wind turbines: neodymium, praseodymium, dysprosium, (samarium);
- in phosphors for energy efficient lighting: lanthanum, cerium, europium, terbium, yttrium; and
- in solar cells: indium, gallium, tellurium.

Five rare earth elements, namely dysprosium, neodymium, terbium, europium and yttrium, as well as indium were found to be critical to U.S. clean energy technologies in the short term.

The U.S. strategy is mainly concerned with diversifying the supply of critical materials for U.S. industry, developing substitutes for the critical materials and improving recycling, reuse and more efficient use of these materials. These three principal goals are expanded to create the eight main points for policy direction with regards to critical materials in the U.S.

1. Research and Development (R&D)

   The importance of R&D for recycling, design for recycling and more efficient use of critical materials, including the reduction of material intensity in products, are highlighted in the strategy as means of increasing supply. Sustained R&D is also considered important in providing breakthroughs in substitute materials or substitute technologies. During the criticality analysis it was demonstrated that for many of these materials demand from other technologies might actually be higher than demand from clean energy technologies, so finding alternatives would be important (at least for other uses). In some cases minimising the amount used in each unit can also make a difference.

2. Information gathering

   While preparing the DOE critical materials strategy, it became evident to the authors that limited information is available on annual production and consumption of rare earth metals, trading prices, materials intensity, and potentials for substitution. Therefore, it is the goal of the DOE to engage a wide range of stakeholders to better understand trends, constraints and opportunities with regards to these materials. The DOE also plans to periodically update demand information for these materials.

3. Permitting for domestic consumption

   It is estimated that the U.S. has important reserves of some of the critical materials, therefore enabling their domestic exploration, extraction and processing is a way of diversifying their supply. At the moment permitting can take 7-10 years, which is reportedly one of the longest periods amongst mining countries. The U.S. strategy recommends closer cooperation between national agencies to minimise the permitting times without compromising public and environmental health and safety.

4. Financial assistance for domestic production and processing

   Very high costs can prohibit domestic exploration, and can force mining industries to move abroad. The DOE suggests providing loan guarantees to domestic miners as well as some kind of price support, to promote domestic mining.

5. Stockpiles

The U.S. National Defence Stockpiling Programme already stockpiles 13 materials and continues to monitor 40 other materials (including gallium, yttrium, tellurium and indium) that are considered critical to defence applications. Due to the uncertainties associated with forecasting, and the substantial upfront costs and downside risks that the government would incur, the U.S. strategy does not recommend stockpiling materials other than those required for defence purposes. It is also recognised by the authors that such stockpiling might distort market price signals by competing with the private sector for materials. However, the strategy does conclude that stockpiling merits further study.

6. Recycling policy

   This relates closely to point 1 on R&D, as research into better collection, disassembly and recycling of products, as well as design for recycling, will be critical. Additionally, the report recommends promoting policies directed towards the end of life recovery of products as well as providing assistance for the development of recycling infrastructure.

7. Education and workforce training

   Without a trained workforce in mining and processing of materials it is unlikely that the U.S. mining and processing sectors will grow. Therefore, the DOE will work with corporations and academic institutions to promote training courses and academic research in the area in an attempt to spur innovation and boost domestic industry. The DOE will also increase its attention on offering internships, scholarships and fellowships in the materials sciences.

8. Diplomacy

   It is considered important to cooperate with partners facing the same challenges, for example with Japan and Europe, to address critical materials needs and reduce vulnerability to supply disruptions. The DOE will also continue to support the work of the U.S. Trade Representative in ensuring that global trading system rules are upheld and transparency in the market is encouraged. The DOE also emphasises the importance of strong diplomatic relations with China to promote diverse, sustainable and economical supplies of materials.

The strategy also summarises a number of programs that are already ongoing in the U.S. with regards to critical materials. One key research institution is the Advanced Research Project Agency – Energy (ARPA-E) that is currently developing substitutes for rare earth magnets, working with GE Global research in developing permanent magnets with lower content of critical rare earths. It is also working with the BEEST programme on a demonstration project on new batteries and storage chemistry, structure and technologies using earth-abundant resources.

The Office of Energy Efficiency and Renewable Energy's (EERE) Vehicle Technologies Program is investigating alternative motor designs that do not use rare earth permanent magnets and also carrying out a second project that is developing a flux coupling motor with comparable performance to a permanent magnet motor. The Program has also made funds available to expand an existing battery recycling facility into a lithium-ion battery recycling facility. Additionally, the EERE makes loans, incentives and tax credits available for clean energy technology development.

3.5.2 Critical Materials Strategy 2011

Similar to its 2010 predecessor, the 2011 strategy assesses whether the short and medium term deployment of wind turbines, electric vehicles, solar cells and energy efficient lighting, and thus the increased demand for the materials they use, is likely to make the supply of these materials critical (U.S. DOE, 2011). The materials selected for this assessment include the 14 elements and materials discussed in the 2010 report as well as nickel and manganese, which are used in batteries. The strategy also includes some discussion of technologies that are notable because they might contribute significantly to key material demand in the long term, namely grid storage batteries, fuel cells, nuclear power, magnetic refrigeration, catalytic converters, gas turbines and vehicle light weighting. Although these are not discussed in great detail the authors note that they might be considered in future revisions to this strategy.

In order to assess whether more widespread deployment of these technologies would result in imbalances to supply and demand of rare earths and other important minerals and metals, projected levels of demand for each material were compared to projected levels of supply. For most materials the supply-demand picture was very similar to the one in the 2010 report with three main differences:

1. Significant supply shortfalls were recorded for lanthanum, cerium and europium in 2010 but the analysis shows that this is a temporary effect;

2. Due to lower material content in photovoltaic (PV) technologies the supply-demand picture for indium, gallium and tellurium is slightly better than depicted in the 2010 report; and

3. In the short and medium terms, significant supply-demand mismatches are projected for europium, terbium and yttrium used in lighting phosphors as demand is projected to spike between 2012 and 2014.

Overall, the same elements that were found to be critical in the 2010 report were still identified here.

The last chapter of the report contains a detailed description of the DOE's activities in the area of critical materials as well as the future policy directions. An interagency working group, convened by the Office of Science and Technology Policy (OSTP), is focussing on critical material prioritisation, R&D and information. Its activities include:

- The identification and prioritisation of critical materials for defence and civilian applications;
- The identification of research investment priorities (including training priorities) and establishment of linkages between research programmes;
- Carrying out bilateral and international dialogues to increase transparency in global trade and identify opportunities to build and share knowledge in extraction and use; and
- Data collection and dissemination.

The 2011 strategy also contains a detailed description of DOE’s R&D programmes. Most research effort has focussed on developing substitutes, specifically for rare earths in permanent magnets for motors and generators, as well as for photovoltaic cells, batteries and phosphors. The Office of Energy Efficiency and Renewable Energy funds the Vehicle Technologies Program, the Wind Program, the Solar Energy Technologies Program and the Advanced Manufacturing Office whereas the Advanced Research Projects Agency – Energy carries out high-risk transformational energy research. In addition to the programmes and projects carried out within the government structures, the DOE also supports research carried out at various national laboratories.

Nation	Goal	Business Policy	R&D Policy	Materials of Interest
Japan	Secure a stable supply of raw materials for Japanese industries	• Funding for international mineral exploration • Loan guarantees for high risk mineral projects • Stockpiling • Information gathering	• Substitution research funded through METI and MEXT • Exploration, excavation, refining and safety research funded through JOGMEG	Ni, Mn, Co, W, Mo, V**
European Union	Limit the impact of potential material supply shortages on the European economy	• Mineral trade policy for open international markets* • Information gathering* • Land permitting streamlining* • Increased recycling regulations*	• Increased material efficiency in applications • Identification of material substitutes • Improved end-of-life product collection and recycling processes	Sb, Be, Co, Ga, Ge, In, Mg, Nb, REEs, Ta, W, PGMs, Fluorspar and Graphite
Netherlands	Reduce material consumption to prevent global shortages by employing ‘managed austerity’	• Government-industry cooperation on material policy through the M2i institute	• Substitutes of abundant or renewable materials • Processes for recycling depleting materials • Study consumption patterns as a result of policy	Ag, As, Au, Be, Bi, Cd, Co, Ga, Ge, Hg, In, Li, Mo, Nb, Nd, Ni, Pb, Pd, PGMs, REEs, Re, Ru, Sb, Sc, Se, Sn, Sr, Ta, Te, Tl, V, W, Y, Zn, Zr

China	Maintain a stable supply of raw materials for domestic use through industry consolidation, mitigating overproduction and reducing illegal trade	• Taxes and quotas on REE exports • Prohibition of foreign companies in REE mining • Industry consolidation • Unified pricing mechanisms • Production quotas • Moratorium on new mining permits until mid-2011	• Rare earth separation techniques and exploration of new rare earth functional materials • Rare earth metallurgy; optical, electrical and magnetic properties of rare earths; basic chemical sciences of rare earths.	Sb, Sn, W, Fe, Hg, Al, Zn, V, Mo, REEs
South Korea	Ensure a reliable supply of materials critical to Korean mainstay industries	• Financial support for Korean firms at oversees mines • Free Trade Agreements and MOUs with resource-rich nations • Stockpiling	• Recycling end-use products • Designing for recyclability • Substitute materials • Production efficiency	As, Ti, Co, In, Mo, Mn, Ta, Ga, V, W, Li and REEs
Australia	Maintain investment in the mining industry while fairly taxing the depletion of national resources	• Low tax on the value of extracted resources • High tax on mine profits • Tax rebates for mineral exploration • Fast turnaround for land permit applications	• Promote sustainable development practices in mining	Ta, No, V, Li and REEs

Canada	Promote sustainable development and use of mineral and metal resources, protect the environment and public health and ensure an attractive investment climate	• Promote recycling industry and incorporate recycling as part of product design • Require accountability in environmental performance and mineral stewardship • Use life-cycle-based approach to mineral management and use	• Provide comprehensive geosciences information infrastructure • Promote technological innovation in mining processes • Develop value-added mineral and metal products	Al, Ag, Au, Fe, Ni, Cu, Pb, Mo

Table 9 Summary of raw materials strategies (U.S. DOE, 2010 and U.S. DOE, 2011)

* proposed policy

** current reserves

3.6 Canada

The responsibility for resource efficiency and resource security in Canada is split between the Federal Government, responsible for Canada-wide policy, and the Provinces and Territories responsible for local policy and implementation. At the Federal level, research is ongoing on recycling, reuse and refurbishment of electronic equipment and design for recycling/remanufacturing, through the Enhanced Recycling Program[2]. The goal of the programme is to make Canada a competitive country for recycling expertise, products and materials. Projects within the programme are subdivided into seven categories: policy and data analysis, greenhouse gas emissions, municipal scrap metal, recycling end-of-life electronic equipment, other product-specific recycling, construction & demolition, buildings sector and metal recycling technology. Work on recycling is also taking place at the province/territory level as is demonstrated by Quebec's Recyc-Québec Agency which offers funding to programmes, industry, organisations and institutions to promote recycling, develop new recycling technologies facilities and expand new markets for recycling products[3].

Two of Canada's most resource-rich areas are found in Manitoba province and Ontario. Manitoba's Department for Innovation, Energy and Mines is responsible for all resource exploitation and since there is little primary manufacturing in the province, minerals are generally exported[4]. In Ontario, the Ministry of Northern Development and Mines oversees vast reserves of resources and is also actively promoting new exploration for base and rare earth metals[5]. What is interesting to note, although not surprising given the resource-rich nature of Canada, neither of these two areas are concerned about resource security as their reserves are expected to last for decades.

3.7 Japan

Japan's strategy for rare metals was released by its Ministry of Economy, Trade and Industry (METI) in July 2009 and its main aim is to ensure stable supplies of critical metals to Japan to maintain and strengthen the competitiveness of Japan's manufacturing industry (METI, 2009). The strategy recommends that the Japanese government takes a focussed and strategic approach to determine which metals are critical to the economy and analyse how to ensure sufficient supplies for the future. According to the strategy there are 'four pillars' for securing critical metals.

Pillar 1: Securing overseas resources

---

[2] http://www.nrcan.gc.ca/minerals-metals/business-market/recycling/research-development/3586
[3] http://www.recyc-quebec.gouv.qc.ca/client/fr/accueil.asp
[4] http://www.manitoba.ca/iem/
[5] http://www.mndm.gov.on.ca/default_e.asp

Japan already invests in mining developments overseas and the strategy recommends that this continues and efforts are strengthened. The Japan Oil, Gas and Metals National Corporation (JOGMEG) can be used as a means of doing this.

Pillar 2: Recycling

This will be achieved by recycling both scrap and post-consumer products, and by better utilising the existing recycling system and establishing a new one if necessary. Recognising the difficulties associated with recycling the critical metals in some of the products, the Japanese strategy calls for promoting research and development of recycling technology.

Pillar 3: Development of alternative materials

According to the strategy, it is important to promote government-industry-academia partnerships and invest in R&D activities that will lead to nanotechnology based applications of alternative materials.

Pillar 4: Stockpiling

Japan stockpiles 7 critical elements to cover 42 days of consumption, in addition to its own private stocks which cover 18 days of consumption (APS/MRS, 2011). The strategy calls for the Japanese government to be flexible when it comes to stockpiling and to increase or decrease its reserves according to market trends and recycling progress. This of course will require monitoring of trends of already stockpiled materials and of those considered critical for industry.

In addition to the strategy, Japan also published a set of guidelines for government to follow when securing natural resources, including critical metals. In this document it is recognised that often Japanese companies wishing to acquire exploration or development interests overseas are faced with the need to negotiate with the target country's government or state-run companies (METI, 2008). According to the guidelines, this will require the direct participation of the Japanese government in order to ensure that the government of the target country is acting in accordance to international contract rules.

Similarly, the Japanese government is expected to support Japanese companies investing in projects abroad. The type of support that is expected varies according to the type of project. For example, for a company that is investing in new exploration agreements abroad, the government should provide support particularly when it comes to risk insurance and other financial instruments. In the event when a Japanese company has an ongoing contract abroad the role of the government becomes one of ensuring the due implementation of the contract. The Japanese government is also expected to develop more cooperative relations with countries approaching it in the hopes of beginning to develop their own natural resources, in the form of education, infrastructure and human resource development.

3.8 Korea

Korea has limited natural resources, limited mineral supporting industry and weak recycling (MIT, 2010). Speciality metals are typically imported from China by Japan, where the ‘materialisation’ stage takes place i.e. where the raw materials are converted into refined materials and alloys. Japan then sells these refined materials to Korea which in turn uses them to manufacture finished products to export and use domestically. At end of life, the waste is either lost or sent to China or Japan for recycling. Japan then recycles it and sells the products back to Korea.

One of the main goals of Korea’s rare metals strategies is to implement policies that will promote recycling and so make Korea self-sufficient in critical metals. The government has set the following ambitious goals for 2018 (relative to 2009): to increase self sufficiency in materials from 12% to 80%, to increase their technical level from 60% to 95% and to increase the number of specialised companies founded from 25 to 100.

In total, 11 elements (In, Li, Ga, REEs, PGMs, Si, Mg, Ti, W, Ni, Zr) were determined to be strategically important for the Korean economy, and four main strategies have been put in place to secure their supplies:

1. Securing foreign/overseas natural resources

   This involves gathering information and dispatching teams for exploration, forming strategic alliances with other countries (such as the Korea-China Material Industry Committee), investing in overseas mines and modifying regulations to encourage investments in foreign developments.

2. Securing domestic natural resources (stockpiles)

   Korea actively stockpiles 21 elements to cover 60 days of domestic demand (APS/MRS, 2011). The strategy calls for an increase in volume of strategic stockpiles (as long as it makes financial sense) but using a flexible approach.

3. Focusing on R&D for materialisation (reduction/replacement)

   Korea decided to focus its R&D efforts on 40 technologies that use the 11 elements that were identified as strategically important for its economy. The 40 technologies fall into four groups: resource extraction (refining and smelting), materialisation (processing and treatment), alternative resources (recycling) and substitution and use reduction. Korea plans to invest $300 million over 10 years in these technologies. For technologies that have long been commercialised in

Korea (such as technologies for indium and PGMs) the emphasis will be on building and enhancing collaboration between producers and consumers, whereas for new technologies the government will establish new capital-intensive R&D projects and industries.

4. Circulation technology and infrastructure (recycle/reuse)

   Recycling efforts will focus both on scrap produced during manufacturing of materials and products, and on recycling at end of life of products. The government will also implement appropriate regulation to enhance collection and increase awareness of the recycling potential of consumer products through their 'urban mining' strategy.

To successfully develop infrastructure and R&D to meet Korea's strategic goals, the government is taking the approach of providing funds and tax incentives to selected industries until they are well established. Korea is also investing in workforce education by establishing international collaborations and providing funding for graduate studies in critical metals technologies.

3.9 Taiwan

In 2002, Taiwan's Environment Protection Administration (EPA) launched its Zero Waste Programme (EPA, 2010). This aims to respond to the issues of global resource and energy depletion and promote more sustainable material use through the implementation of a more cyclic approach to waste management. Technological metals and materials are included in the resources of concern and are one of the waste groups tracked through Taiwan's Industrial Waste Control Centre. While the primary goal of the centre is to track industrial waste flows, the EPA found that within a few years of its operations it caused a decrease in actual waste quantities. Additional work on sustainable resources is carried out through Taiwan's promotion of Environmental Science and Technology Parks to promote resource use, recycling and recovery.

Taiwan's focus on tackling electronic waste is evident in the commissioning of the UK-Asia Pacific Electronic Waste Management GPF Project for 2011/2012, due to report in 2012, which aims to bring together experts and key stakeholders in electronic waste and the wider sustainable material management agenda to tackle the growing electronic waste problem (British Embassy Taiwan, Pers. Comm.).

A government reform is expected in Taiwan in 2012 which will result in the new Ministry of Environment and Resources (MOER), whose responsibilities will include environmental protection and mineral management. Resource efficiency and security issues are expected to be a key task for the new ministry.

4. Other Research on Resource Security

In addition to the national strategies and the supporting research presented in Chapter 3, other relevant work, carried out by academic institutions, consultancies and environmental programmes, is also available. This chapter aims to summarise some other important research in the area of resource security.

4.1 United Nations Environment Programme (UNEP)

UNEP's International Panel for Sustainable Resource Management (the International Resource Panel, IRP) was established to 'a. provide independent, coherent and authoritative scientific assessments of policy relevance on the sustainable use of natural resources and in particular their environmental impacts over their full life cycle; and b. contribute to a better understanding of how to decouple economic growth from environmental degradation' [6]. This section summarises three relevant IRP reports dealing with the issue of resource security.

4.1.1 Priority Products and Materials Report

In 2010 the IRP published a report that aimed to identify those economic activities that have the greatest impacts on the environment by studying and analysing existing literature (UNEP, 2010). This was done by considering five separate factors: identification of the most critical uses of natural resources and their impacts (i.e. focus on pressures), determination of the main industries that contribute to environmental and resource pressures (i.e. focus on production), assessment of the consumption categories and product groups that have the greatest impact across the lifecycle (i.e. focus on products and consumption), assessment of which materials have the greatest impact across their lifecycle (i.e. focus on materials and resources) while at the same time taking into account socio-economic trends and development and their likely impact on priorities.

The results from this report show that agriculture and food consumption together with the use of fossil energy carriers for heating, transportation and the production of manufactured goods are key priorities for improvement. Since the study found that impacts increase with increasing affluence, impact reduction strategies will require a change in production and consumption that will most likely include the use of clean technologies, low impact products and low impact materials. Nonetheless, the study concludes that very often new technologies for energy supply and mobility, such as electric vehicles and solar panels for energy production, require the use of metals, the refining of which is energy intensive. However, these issues have not been studied sufficiently to allow for better conclusions to be drawn. Finally, the report

[6] http://www.unep.org/resourcepanel/introduction.aspx

calls for a harmonised way of collecting and reporting data that will allow for easier comparison and analysis in the future.

4.1.2 Decoupling Report

The report on Priority Products and Materials was complemented by another IRP report on decoupling resource use and environmental impacts from economic growth. The report aims to clearly define what decoupling is, to assess whether decoupling is already taking place, to identify technological and economic driving factors to decoupling and provide an indication of the types of policy measures and considerations that will be necessary to promote decoupling (UNEP, 2011b).

The report notes that substitution can be a very effective decoupling strategy but has limitations as certain materials have specific characteristics and properties that make them uniquely adapted for certain uses. Additionally, particularly in the case of metals, we use almost all the metals available to us for various purposes. Therefore, substitution of one with another would most likely not lead to decoupling.

According to the report, reducing resource use can be the most effective strategy to achieve decoupling, particularly as materials approach certain limits. For example, as mineral ore grades decline, more energy is required for their extraction. Therefore, reducing resource use would not only lead to less mining but would also prevent the use of significant amounts of energy. However, the report notes that resource use reductions will depend on the level of investment in innovation for more sustainable use of resources. The IRP is planning to release a second decoupling report that will focus on this issue.

4.1.3 Metal Stocks and Recycling Rates Report

Recycling is one way of reducing resource use. The IRP investigated this possibility by commissioning two projects to look into stocks and recycling rates for metals. The results of these projects were summarised in a booklet called ‘Metal Stocks and Recycling Rates’ published in May 2011 (UNEP, 2011a).

The IRP reviewed metal stocks and recycling rates for 60 metals in the ferrous, non-ferrous, precious (including silver, gold and platinum) and speciality groups (including REEs and others identified as critical for emerging technologies). It found that while in-use stocks for copper and aluminium are well understood, there are too few studies that show temporal and spatial in-use of other metals, such as critical metals. According to the IRP, a way of moving to a sustainable metal strategy is to move from physical mines to ‘anthropogenic mines’ in all industrialised, emerging and developing economies. These ‘anthropological mines’ include already known urban stocks, such landfills and recycling stocks, as well as hibernating stocks, such as unused copper cables.

Whether the recyclate comes from old or new scrap can affect recycling rates. New scrap, which is generated during manufacturing of products, is fairly easy to recycle and has clear economic and resource benefits to the company. On the other hand, old scrap, which arises from products at EoL, might take years or decades to enter the waste stream and can be so diluted or mixed together with other materials (such as plastics) that recycling might not be possible. Furthermore, it is easier to recycle from industrial applications than from consumer applications, which is demonstrated by the recycling rates of many metals.

Finally, the report identifies three urgent issues to help increase metal stocks and recycling rates, the first of which is R&D. The IRP calls for more governmental funding for data acquisition and analysis to identify urban mines, and to carry out recycling technologies research such as recycling demonstration plants and closed-loop recycling of rare earths from batteries. The second urgent issue is to stop illegal waste transport to countries that lack recycling infrastructures. Finally, the report calls for continuous improvements of legislative systems to enable better recycling rates for many metals and post-consumer products.

4.2 Organisation for Economic Co-operation and Development

The OECD's Working Group on Waste Prevention and Recycling (WGWPR) has been exploring whether Sustainable Materials Management (SMM) is a useful concept for policy-making, through applying it to four case studies focussing on wood fibre, aluminium, non-packaging plastic waste and critical metals in mobile devices. The reports of all four case studies are available on the OECD website[7].

The work on critical metals in mobile devices was divided into two phases; phase 1 reported in 2009 and phase 2 is due to report at the beginning of 2012. The aim of Phase 1 was to analyse the environmental impacts of critical metals throughout their lifecycle and to explore policy opportunities and barriers for SMM as a way of demonstrating the utility of the concept for policy making (OECD, 2009). The case study was built on existing data and no primary work took place. The metals of interest were antimony, beryllium, palladium and platinum and the main focus was on the economic and environmental aspects of sustainability. The scope of the work was to create an analytical framework that could be modified for other consumer electronic products.

Consideration was given to the entire life cycle of mobile phones, from extraction and refinement of the metals to refurbishment/reuse of the phones to recycling and final disposal and all the steps in between. For each stage of the lifecycle policy

[7] http://www.oecd.org/document/29/0,3746,en_2649_34395_44403037_1_1_1_1,00.html

considerations, economic, environmental and social implications and key information gaps were identified.

Several important conclusions were reached:

- The sorting stage that follows collection optimises device reuse, which is a key economic driver in sustaining these programmes;
- There may be a preference on the part of original equipment manufacturers to encourage recycling over reuse in order to encourage new product sales;
- Interim processors play an important role in which the disassembly of used mobile phones leads to parts reuse, removal of contaminants and material recovery;
- Facilities that are efficiently operated and achieve maximum recycling yields should be competitive enough on the world market to procure sufficient feedstock, though companies that operate with lower standards create an uneven playing field; and
- Since informal recycling in developing countries has negative environmental and health consequences, it is imperative that environmentally sound management capacity be developed because the number of mobile phones in Asia and Africa is rising very quickly.

The key policy-relevant points coming out of this report are as follows:

- The benefits and costs of mobile phone use or recycling/disposal are unevenly distributed across the environmental, social and economic dimensions, particularly in developing countries;
- The lifecycle approach to supply chain management is extremely beneficial;
- Even if complete capture of all mobile devices and maximum recycling of the metals they contain were achieved, there would still be the need for primary mining to meet growing demand for the services metals provide;
- In the lifecycle of consumer electronic devices, the design stage is of critical importance. Decisions made at this stage will have direct economic and environmental impacts when the devices are recycled; and
- The mobile phone industry has demonstrated a tremendous capacity for rapid technological change. Specifically the introduction of new materials may impact future reuse and recycling activities. In this regard, technological innovation is an important policy driver.

The research also identified a number of knowledge gaps related to, among others, the environmental impacts of the materials across their lifecycle, the global flow of mobile phone devices, the fate of critical metals upon disposal of the products to landfill, costs and processes regarding refurbishment and reuse and behavioural issues such as why do people hoard mobile phones and what would encourage them to give them up.

4.3 World Economic Forum

The World Economic Forum's Risk Response Network has commissioned a project, called 'The political and economic implications of resource scarcity', which aims to bring together global stakeholders from government and industry to understand the implications of resource security and develop a set of recommendations for policy to help address the risks (WEF RRN, 2011). The project's methodology consists of detailed research, workshops, interviews and data analysis to not only identify the current state of global resources but also to understand the global trends in resource use and interactions between factors affecting resource security.

The project, which commenced in early 2011, is ongoing and workshops and meetings are planned throughout 2012 with the final report being launched in September 2012. As events take place, their outputs (in the form of summaries or reports) are made available through the project's website. Of these outputs, perhaps the most pertinent to the issue of resource security, is the 'Global Risks Meeting Report' resulting from the Workshop held in New York on the 6th and 7th of April 2011. Around 80 decision-makers and experts form a range of sectors (both public and private) gathered in New York for this 2-day workshop to discuss and determine ways to manage, prepare for and respond to global risks.

One of the issues discussed was the recent earthquake and tsunami and resulting nuclear crisis in Japan. It was noted that in addition to the environmental, economic and social disruptions that occurred domestically, the event also had global implications, particularly in the U.S., Europe and Asia as it disrupted the operations of a number of companies that supplied parts, especially for the automotive and electronic industries, to these countries. Nonetheless, it was noted by a Japanese official that the affected region only produces about 2% of Japan's GDP so overall, the impact to the economy was quite small. This example offers an important demonstration for the need for governments to establish an 'inventory of relief equipment' that would identify alternative countries/companies that could provide relief equipment at the time of need. The disaster in Japan also demonstrates the need for government institutions and companies to have in place a culture of risk awareness and be prepared for various disruption scenarios. As the earthquake and tsunami in Japan was the first event of this magnitude to be broadcasted globally through the use of social media, the importance to provide real-time data to respond to crises was also noted.

The issue of supply chain and transport risk was also discussed during the meeting as recent events (the Japan catastrophe, and the volcanic ash in Europe in 2010) highlighted some of the risks associated with it. The workshop participants identified a number of issues that can reduce risks and vulnerabilities, one of which was the quantification of risks, as a greater understanding of the risks could lead to better action to address them. Better coordination between the private and public sectors, the need for more integrated and local risk management capabilities, the need for a centralised information repository for transportation in the wake of a crisis and proper pricing were other possibilities.

Another point of discussion during the workshop was resource security. It was noted that the important linkages and relationships between various issues that affect resource security, namely geopolitical, climate change, urbanisation, waste and technology, must be considered to a greater extent in the future and not just in isolation. Resource security should also be considered at a global rather than a local level. This is particularly important as resource risks have the potential to cause further price increases, conflict, more urban migration and important environmental controls.

At this point, it is worth bringing to the reader's attention the Global Risk reports published every year by the WEF Risk Response Network. These reports summarise the results from a survey and workshops that reflect the opinions of experts and stakeholders from industry, government, academia and civil society worldwide on which risks, across several risk categories (i.e. economic, environmental, geopolitical, societal and technological), are more important in terms of likelihood and in terms of impact for the next 10 years. Although, these reports do not go into any detail with regards to the issue of resource security, the differences in perceived risks from one year to another are noteworthy and demonstrate what is in people's mind at a given time. For example, while environmental risks were considered most likely by respondents in the Global Risks 2011 report, respondents in the Global Risks 2012 report consider economic risks to be more likely. Similarly, economic and environmental risks were perceived as having the greatest impact in the 2011 report, whereas these have been displaced by economic and societal in the 2012 report (WEF, 2012).

4.4 McKinsey Global Institute

Global demand for resources is continuously on the rise while supply and access to resources is becoming in many cases increasingly more difficult. This McKinsey report discusses these points and illustrates via three scenarios how the world might meet its resource requirements (Dobbs *et al.*, 2011).

The price of key resources fell by almost half over the past century, mainly due to technological advances but also due to the discovery of new, low-cost sources of supply. Additionally, in some cases resources were not priced to reflect their full cost of production (for example due to subsidies for energy or the availability of free water) or the externalities associated with their use (for example carbon emissions). This was happening despite the fact that within this period demand for resources increased between 600 and 2,000 percent due to the quadrupling of the global population and a 20-fold increase in global economic output.

However, this changed over the past decade, when high volatility in resource prices was observed. The resource landscape is likely to change dramatically over the next 20 years due to the fact that:

1. Middle class consumers are expected to increase by 3 billion over the next 20 years (in addition to the existing 1.8 billion). This increase is driven by rapid economic development in emerging markets, such as in China and India, whose growth is happening faster and at a greater scale than any we have experienced so far. This will increase the demand for cars, infrastructure and high-level nutrition.
2. While demand is increasing, discovery and extraction of new supply sources is becoming more difficult and expensive. Supply for key resources is becoming inelastic which in turn can lead to increased volatility. This trend is likely to persist as resources are becoming depleted and new sources are either inaccessible or less productive. Nonetheless, the authors do note that historically the risk of shortages has acted as a catalyst for innovation.
3. Resources are increasingly linked, more so now than at any other point and these linkages are expected to become more important. This means that a supply shortage or price change in one resource can impact the supply and price of other resources.
4. Production is constrained by environmental factors. For example, the Economics of Climate Adaptation Working Group found that due to existing climate change patterns, some regions are at risk of losing 1-12% of their GDP annually by 2030.
5. The rapid diffusion of technologies, such as mobile phones, has given a stronger political voice to a large share of the population that lack access to basic needs such as energy, water and food. This has led to a stronger concern about global inequalities.

Overall, the growing demand for key resources, higher prices and greater price volatility as well as tighter markets are likely to lead to slow economic growth, social unrest and damage to the welfare of citizens impacting disproportionally the poor who spend a larger share of their income on energy and food.

The report illustrates three case scenarios of how the global economy might address its expanding need for resources. The first scenario, the supply expansion scenario, assumes that supply of resources will expand to meet demand and compensate for the depletion of existing supply. The report finds that water and land are likely to present the largest challenges, but there will also be capital, infrastructure and geopolitical challenges to face (for example in the case where resources are found in countries with high political risks). Such a rapid expansion to supply could also have a range of negative environmental effects and require additional investments to help the global population address any potential climate change impacts such as desertification and risk of flooding. Nonetheless, it is also noted that there will also be opportunities for innovation. The example of shale gas, where technological advancements have led to its rapid development and resulted in lower electricity prices and the creation of a quarter of a million jobs, is illustrated. However, the environmental effects associated with shale gas are not yet understood. Therefore, it is concluded that a rapid expansion to supply could create both economic opportunities and challenges.

The second scenario, called the productivity response case, assesses a range of opportunities to boost resource productivity and fill the remaining gap with supply. Therefore the need to expand supply is reduced but not eliminated. It finds that up to 30% of the total 2030 resource demand could be addressed through opportunities in energy, water, land, and materials. However, this scenario requires $900 billion per year more in capital than the supply expansion scenario. Nonetheless, this investment could potentially create between 9 and 25 million jobs and, over the longer term, reduce price volatility, encourage investment and promote innovation. The report identified more than 130 resource productivity opportunities, the top 15 of which are:

1.Building energy efficiency	6. Higher energy efficiency in the iron and steel industry	11. Improving end-use steel efficiency
2. Increasing yield of large-scale farms	7. Increasing yields in smallholder farms	12. Increasing oil and coal recovery
3. Reducing food waste	8. Increasing transport fuel efficiency	13. Improving irrigation techniques
4. Reducing municipal water leakage	9. Increasing the penetration of electric and hybrid vehicles	14. Shifting road freight to rail and barge
5. Urban densification (leading to major transport efficiency gains)	10. Reducing land degradation	15. Improving power plant efficiency

These 15 opportunities would deliver about 75% of the resource productivity potential whereas the top 3 alone would deliver about a third.

In order to achieve a pathway that will maintain global warming within the limits suggested by the IPPC, carbon emissions would need to be reduced from the 48 gigatonnes per year emitted in the productivity response case to 38 gigatonnes per year in 2030. Therefore a third scenario, the climate response case, was developed. This would require a shift from high-carbon coal power to the use of more renewable energy sources and biofuels for transport as well as further abatement of carbon emissions in land use. Such a case would require $260-370 billion more than that required for the productivity response case over the next two decades. However, this climate response case will lead to significant welfare benefits and accelerate the diffusion of technology to poorer rural communities. Despite the inevitable increased demand for energy that this scenario will have, carbon emissions will only increase by less than 1%.

Currently, governments take a fragmented approach to dealing with resource supply issues with each department or agency addressing the concerns and barriers that directly affect it, unaware of the full set of resource productivity opportunities. The McKinsey report suggests that, overcoming the barriers will require a transformation of institutional mindsets and mechanisms to develop crosscutting system approaches to the management of resources. Additionally, governments should consider actions on three fronts:

- Strengthen price signals

Many productivity opportunities are not attractive to the private sector, one reason being that there is uncertainty about the future path of resource prices. Another reason is that fiscal regimes in many countries provide a disincentive for the productive use of resources (for example through the use of subsidies and through failing to correctly price the externalities of production). The report finds that removing subsidies for agriculture, water and energy and pricing carbon emissions at $30 per tonne, could improve the attractiveness of productivity opportunities to the private sector. Uncertainty about whether government financial support regarding opportunities in renewable sector will continue leads to investors demanding higher returns to cover their risks. This could be avoided if governments put in place stable, effective policy regimes that strengthen market signals and ensure sufficiently attractive returns to engage the private sector.

- Address (non-price) market failures

Governments can play an important role in overcoming non-price barriers to resource efficiency. One of these barriers is access to capital, particularly as most of the productivity opportunities are in developing countries. Loan guarantees and other risk-sharing tools can encourage financial institutions to lend. Governments also have to ensure that innovation is enabled by removing barriers and investing in more R&D. Government procurement rules can promote green technologies and government can make targeted investments in promoting infrastructure.

- Build long-term resilience

Long term resilience with regards to resource challenges can be achieved by making people aware of the risks and opportunities associated with resources, by putting in place mechanisms to mitigate the impacts of those risks on the poorest members of society and educating both businesses and consumers on the need to adapt their behaviour.

Finally, the report concludes that businesses will also benefit from understanding the risks and opportunities associated with resources and that those businesses which capitalise on the opportunities are the ones most likely to benefit. Furthermore, industry could go one step further by putting in place standards to increase the transparency of the supply chain and the environmental footprint of resources.

4.5 Price Waterhouse Cooper

In December 2011, PwC published a report containing the responses from a global survey they undertook to gather information on how the minerals and metals scarcity is affecting key manufacturing industry sectors, how prepared they are to address the issue and what risks and opportunities they are facing (PwC, 2011). Sixty-nine telephone interviews were carried out with senior executives of leading, high revenue companies (over $2 billion) in Europe, the Americas and Asia Pacific in the sectors of automotive, aviation, chemicals, energy and utilities, high tech, infrastructure and renewable energy.

On average, 68% of the companies interviewed agreed that minerals and metals scarcity is a pressing issue for them, with the highest concern coming from the infrastructure, high-tech and aviation industries. European industries showed greatest concern with regards to the issue of scarcity (79%), followed by Asia Pacific industries (63%) and industries from the Americas (62%). A greater percentage of respondents thought that their suppliers saw metals scarcity as a pressing issue than their customers perceiving it as such. Furthermore, a great discrepancy was observed in the perceived awareness of the governments with regards to metals scarcity with 96% of European industries believing that their governments were aware compared to 58% for Asia Pacific and 54% for the Americas.

When asked whether they consider metal scarcity as a risk for their companies, 58% of all respondents stated that there was a risk at present and 72% consider this to be a risk in the next five years. The risk was perceived to be higher by companies in

Europe than those in the Americas and Asia Pacific. The issue of risk is associated to whether or not the supply of minerals and metals is stable for these industries. Figure 3 shows that the most unstable supply is currently experienced by the renewable energy industry, whereas the aviation and high-tech industries are experiencing relatively stable supplies. On the other hand, almost all industries are expecting to have disruptions to supply over the next five years.

Some respondents also stated that the issue of minerals and metals scarcity also presents some opportunities, with the most positive sector being the automotive one where respondents expect opportunities to increase over the next five years. This and the aviation and chemical industries identified buying power, a co-ordinated purchase policy, substitutes, recycling and extraction, upgrading technology and forward contracts with key suppliers to be some of the possible opportunities. Again, regional differences existed with European industries being more positive than those in Asia Pacific and the Americas.

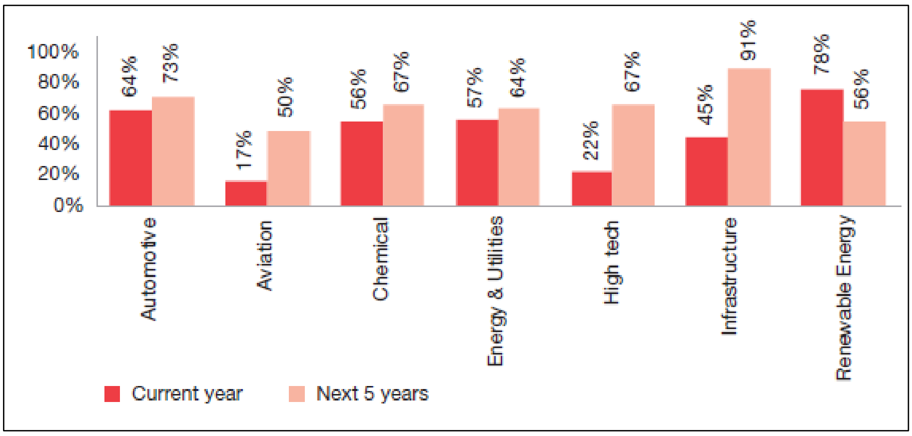

Figure 3 Percentage of respondents who experience the unstable supply of mineral and metals (PwC, 2011)

However, despite these opportunities, 67% of the European respondents said that they will be affected by minerals and metals scarcity. Although this percentage was lower for Asia Pacific respondents at 53%, the severity was perceived to be higher. The most affected sectors at present are the renewable energy, high-tech, and infrastructure. However, all the industries, with the exception of renewable energy and aviation, expect the effects of metals and minerals scarcity to increase in the next five years (Figure 4). The chemical sector expects to see the greatest increase in impact in the next five years. The current and expected impacts arise from the fact that these metals and minerals make a substantial contribution to the product value of these industries. The respondents believe that their first tier suppliers are affected by metals and minerals scarcities but also perceive their customers to be affected, although to a much smaller extent.

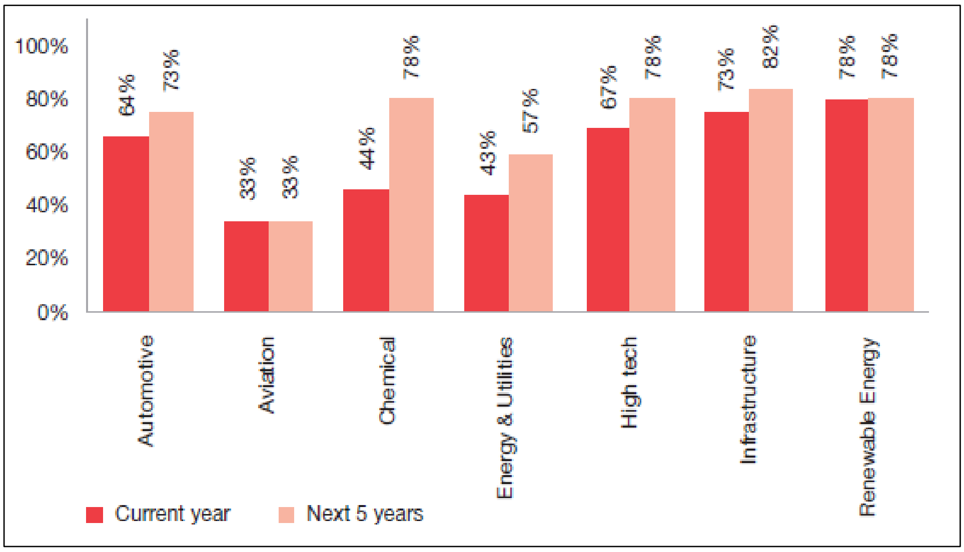

Figure 4 Percentage of respondents indicating that their company is affected by minerals and metals scarcity (PwC, 2011)

The increase in demand for these materials was perceived to be the primary cause for metals and minerals scarcity, with geopolitics and extraction shortages coming in second and third respectively. Although 70% of all industry respondents, except aviation, believed growing demand to be the main culprit for metals and minerals scarcity, the infrastructure industry believes itself impacted by this factor the most, as can be seen in Figure 5. According to these data, a lack of reserves is considered to be a significant impact for the automotive industry, whereas the renewable energy industry thinks that low substitution rate is a significant factor (89% of respondents). This could possibly be attributed to the fact that technologies such as solar cells and wind turbines use metals such as indium and neodymium which are proving quite difficult to substitute. However, interestingly enough only 56% of the respondents in the renewable energy industry thought that there was insufficient R&D in the area of metals and mining scarcity.

The survey also asked the respondents to indicate their company's preparedness to mitigate the impact of scarce metals and minerals and overall 49% said that their company's preparedness was 'high' or 'very high'. The automotive and renewable energy industries indicated the highest level of preparedness, with 64% and 67% of respondents respectively indicating high to very high preparedness. The least prepared industry is the chemical industry with 44% of respondents stating that their company's preparedness is low to very low. At the regional level, European and Asia Pacific companies seemed to be equally prepared to address the issues arising from metals and minerals scarcities by having policies in place to address any risks (75% and 74% respectively reported high or medium preparedness), whereas companies from the Americas seemed to be slightly less prepared (69% reported high or medium preparedness).

Industries	Reserves run dry	Low substitution rate	Growing demand	Geo-politics	Insufficient R&D
Automotive	82%	64%	73%	82%	45%
Aviation	33%	50%	67%	50%	33%
Chemical	78%	78%	89%	89%	33%
Energy & Utilities	57%	79%	93%	93%	64%
High tech	44%	67%	78%	56%	33%
Infrastructure	45%	55%	100%	82%	64%
Renewable Energy	78%	89%	78%	78%	56%
Average	61%	70%	84%	78%	49%

Figure 5 Percentage of respondents indicating the extent to which the factors contribute to the issue of minerals and metals scarcity (PwC, 2011)

In order to address the risks arising from scare metals and minerals, three quarters of the respondents indicated that they collaborate with suppliers and about half indicate that they collaborate with customers. The high-tech and automotive industries reported the highest rates of collaboration with their first tier suppliers (88% and 82% respectively), whereas the aviation industry reported the lowest rate of collaboration at 33%. Interestingly enough, of all the respondents who indicated that their suppliers are ‘highly’ or ‘very highly’ impacted by metals scarcity only 68% have a strong level of collaboration with them.

The best response to the issue of metals and minerals scarcity is seen to be efficiency (75% of respondents) with strategic alliances with suppliers (68%) and diversification of suppliers (67%) also considered important. Relocating production (42%) and increasing the extraction of minerals and metals (55%) rank last. Some differences appear between sectors, with 100% of the renewable sector and 82% of the automotive companies highlighting the importance of resource efficiency. 82% of respondents in the infrastructure industry considered geopolitics to be a suitable measure but only 17% of aviation industries agreed. The high-tech and automotive industries consider more substitution to be a suitable solution. At the regional level European companies consider more reuse, more substitution and more R&D to be the most applicable measure, whereas Asia Pacific and the Americas prefer more resource efficiency and strategic alliances with suppliers.

With regards to how satisfied the respondents are with their company's response to the issue of metals scarcity, 46% said they were 'highly' or 'medium' satisfied, with 58% in Europe, 47% in Asia Pacific and 35% in the Americas. The automotive and infrastructure sectors were the most satisfied whereas the aviation industry was the least satisfied. Overall, almost 75% of the respondents said that substitution technology is the most important facility to help them address the issue of scarcities, with this percentage reaching 91% in the automotive industry. Data information also played an important role for the automotive and infrastructure industries. The infrastructure industry also found regulation to be a useful facility.

4.6 European Research

This section provides the summaries of two projects relating to critical materials in the EU. The first project looks at global availability of selected metals, their recycling potential and recycling technologies, whereas the second one aims to quantify the importance of recycling for the EU economy, including the importance of precious and critical metals. This section also summarises the outputs from a workshop held at the British Embassy in Berlin on the issue of material security.

4.6.1 Öko-Institut e.V. for UNEP

This project came about as a result of a grant signed between UNEP and the EC in relation to UNEP's work on Sustainable Innovation (Bleher *et al.*, 2009). The results were designed to feed into the Marrakech Process (i.e. 10 year framework of programmes on SCP) and hence into the Commission's 2010/11 cycle on Sustainable Development.

The project looked at what it describes as 'green minor metals' (indium, germanium, tantalum, PMG, tellurium, cobalt, lithium, gallium and REEs) and their use in four technology clusters, namely electrical and electronic equipment (EEE), photovoltaic, batteries and catalysts. The three main objectives of the project were as follows:

- To identify and analyse the global availability, geographical spread and prices of critical metals;
- To carry out a comprehensive analysis of their recycling potential and identify gaps; and
- To identify framework conditions that could help to foster technologies which enable the implementation of closed-loop recycling systems for critical metals.

With regards to the criticality assessment, criteria on demand growth, supply risk and recycling restrictions were assessed against the short, medium and long term. In the short term tellurium, indium and gallium were found to be the most critical due to a combination of rapid demand growth, serious supply risks and moderate recycling. Rare earths, lithium, tantalum, palladium, platinum and ruthenium were the most critical ones in the medium term and germanium and cobalt most critical in the long term.

The report also assesses the existing recycling infrastructure in Europe for each of the four technology clusters. With regards to industrial catalysts there is mature infrastructure throughout the world and most often the suppliers of catalysts are also their recyclers. In recent years, the infrastructure for pre-consumer photovoltaic waste has been initiated or improved but post-consumer recycling has not yet been developed. On the other hand, due to the Battery Directive, battery collection systems have been initiated in Europe and further improvements are still expected. A similar situation exists for EEE but further development is necessary to optimise recycling of metals in heterogeneous applications. For both batteries and EEE, the report finds that there is a serious lack of infrastructure in developing countries.

The report offers some suggestions on how recycling can be promoted to ensure the supply of critical metals:

- Enlargement of recycling capacities

  Successful technologies for the recycling of a number of critical metals are available in Europe and Japan but existing capacities will not be sufficient in the future. The examples of PGMs in automotive catalysts, indium in LCDs and solar and tellurium in photovoltaic applications are given.

- Development and realisation of new recycling technologies

  There is a need for research and development of new procedures particularly for tantalum in dissipative EEE applications such as cell phones, rare earths and lithium.

- Accelerated improvement of international recycling infrastructure

  There is a lack of take-back and collection systems for post-consumer waste. There is a need for know-how and technology transfer from developed countries to developing economies.

Other conclusions and recommendations from the report include:

- Research and development of technologies for specific materials in different applications;
- Monitor and control illegal scrap exports containing critical materials;
- International cooperation to transfer knowledge to developing countries since

they have increasing stock of used products; and

- To increase close-loop recycling:
    - financial support from EU regarding R&D on recycling technologies and demonstration plants;
    - investment to support development of large scale recycling plants;
    - continuous improvement of EU legislation system to ensure recycling and recovery of critical materials;
    - establish best-practice guidelines for the recycling value chain including product design, collection, dismantling and pre-treatment;
    - Campaigns and initiatives to draw the public's attention to critical materials and to encourage them to recycle e.g. cell phones stored at home; and
    - technology transfer.

4.6.2 European Topic Centre on Sustainable Consumption and Production

This project tried to quantify the economic importance of recycling for the EU economy, taking a view of the amounts of materials recycled, the turnover of the recycling industry and job creation (ETC/SCP, 2011). The following waste types were considered: paper & cardboard, plastic, iron & steel, aluminium, copper and nickel, precious metals (a very aggregated category including gold, platinum, silver and many others), other metals (a very aggregated category including lead, zinc, tin, tungsten, molybdenum, cobalt, cadmium and others), glass, electrical and electronic equipment, and construction & demolition (represented by concrete). A special focus was placed on the question of current and future needs of rare metals.

With the exception of precious metal wastes, the import of recyclables into the EU has been quite stable over the years 2000-2009 and on a much lower level than exports. The turnover of recycling in the EU increased from 32.5 billion Euros in 2004 to 60.3 billion Euros in 2008. Due to the economic crisis, 2009 saw a decline in turnover from recycling, but the report notes that this was related to the decreasing unit prices and not to the recycled amounts.

The report then tried to estimate what percentage (based on weight) of consumption is currently covered by the recycling of each of the waste types as well as what percentage could be covered if all the recyclable waste was recycled (although the authors do recognise that for many of these waste streams 100% recycling rate is not possible). The results, which are summarised in Figure 6, show that:

- Paper & cardboard and iron & steel are the most exploited waste resources and this is due to their ease of collection and their value.

- Plastics and WEEE are the least exploited resources, both currently and potentially. For plastics this is due to the difficulties associated with their sorting and thus the quality of the product but also due to its high heating value which makes it a suitable feedstock for incineration. For WEEE, the low recycling rates can be attributed to the large volumes of second hand EEE that are exported from the EU as well as the increase in EU stocks.

- Aluminium also presents relatively low recycling rates due to its high consumption but also due to the fact that, its use in construction, domestic stock is increasing.

With regards to the turnover related to the value of total consumption, paper & cardboard covers more than 45% while iron & steel and other metals cover about 10%. Aluminium and copper cover 5-10% whereas plastic and glass cover less than 5%. There are no available figures for WEEE and concrete. In terms of turnover of domestic recycling related to turnover of EU production, the economic importance is larger for paper & cardboard and other metals, whereas it is on the same level for iron & steel, aluminium and glass. For copper and plastic the importance is lower because recycling of these two materials mostly takes place outside the EU.

The report also includes an analysis of employment trends and recycling, although it is noted that there is a substantial shortage in information availability. Employment relating to the recovery of materials in the EU has been steadily increasing from 177,000 people in 2000 to 301,000 in 2007 (figures do not include employment linked to the processing of all materials as information was not available). Overall, the report concludes that the available information does not allow for any conclusions to be drawn regarding the trend of employment in the waste collection sector and the rate of collection.

The report also contains a section focussing on rare metals and their importance for the EU green economy. This section summarises criticality assessments, current use and future demand information found in other reports summarised earlier (and so will not be repeated here). It also emphasises the fact that, since the EU has no or very little domestic production of these metals, recycling them will be crucial for the green economy. However, due to their dissipative use it will be necessary for policy makers to put in place infrastructure for the collection and recycling of these metals and for industry to design their products for recycling and ensure that they are in fact recycled.

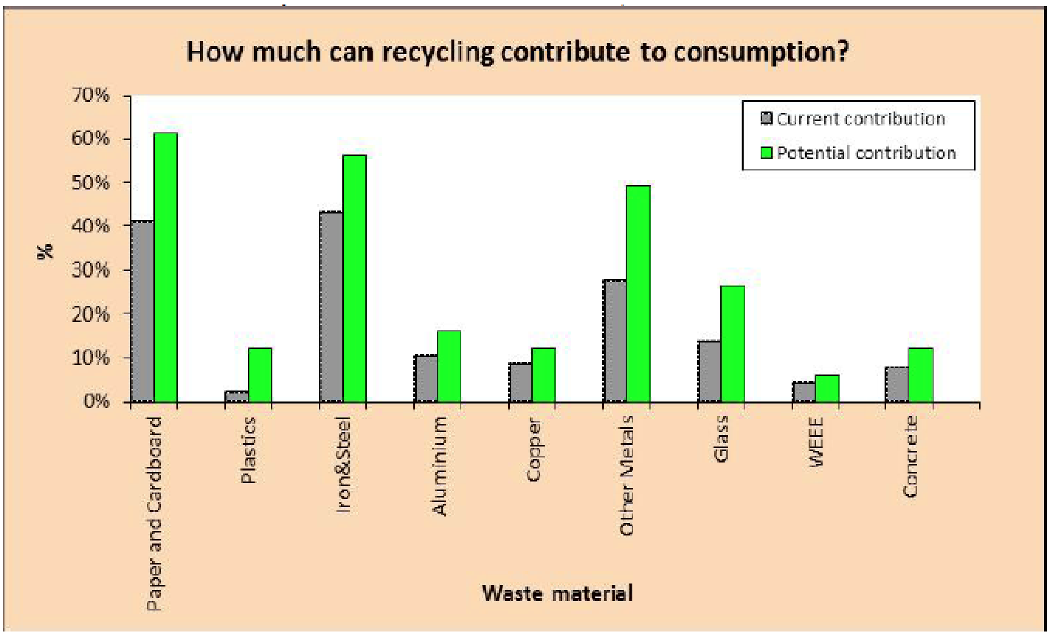

Figure 6 EU's recycling contribution to EU's consumption (% for 2006) (ETC/SCP, 2011)

4.6.3 Resources that Don't Cost the Earth – Workshop

The UK's Science Innovation Network (SIN) operating in Germany and the Technology Strategy Board's Materials Security Special Interest Group (SIG) organised a two-day workshop in Berlin that brought together European stakeholders to discuss the issues and opportunities regarding material security and exchange best practices across Europe (SIN and Technology Strategy Board, 2011).

The introductory/overview part of the workshop consisted of three keynote presentations. The first one, from the German mineral resources agency (DERA), described those metals that are critical to the German economy and gave an overview of the reasons why some metals are considered critical (i.e. geopolitics, reserves, demand etc.). This was followed by a presentation by the British Geological Survey (BGS), which highlighted the shortcomings of the fixed stock approach to calculating resources and reserves. The BGS presentation also made the point that exploration investment in Europe is very low compared to the rest of the world. Furthermore, despite the fact that recycling will be important to meet the future demand for critical materials, it will not be enough on its own and virgin sources will remain the main material source. This brings to light the challenges associated with critical materials since the knowledge base about them is quite small. The presentation also makes made the point that although Europe has good geological potential for these materials, there are problems associated with access to land. BGS also raised the issue of the need for more skilled personnel and more research on metallogenesis and exploration methods. The industry perspective was given by the Design for the Environment Working Group of the ADS Trade Organisation (a trade organisation advancing UK aviation, defence, security and space industries globally). The main point arising from this presentation was the need to assess criticality at the business and sector level for specific industries.

The workshop was then split up into four parts, each dealing with one of four key areas of material security and comprised of a set of presentations followed by discussions. Although, at the time of writing this report, not all the presentations were available to view online, this section aims to summarise the main points from the workshop. According to the group's website, the full workshop report will be published in due course.

Part I: Securing access to rare resources – extraction and partnerships

The presentations in this section outlined some of the strategies for securing access to critical materials in the future, including:

- Investing more in exploration, including exploring new terrains and using technological innovations to find new reserves;
- Re-evaluating existing deposits, such as deposits that were not accessible due to political or physical position and deposits that were previously deemed as non-viable;
- Collaborating with supplying nations to ensure access to resources. An example of how this can be achieved is available in the presentation by the Hague Centre for Strategic Studies: the Netherlands is cooperating with Japan, China, Australia, the US and Congo to gain access to resources in exchange for providing their expertise in other areas such as water recycling;
- Industry-driven sourcing where companies invest abroad to ensure access to resources;
- Developing national raw materials' strategies to outline how business and government can collaborate to ensure access to resources across the supply chain;
- Replenishing live reserves through prolonging product lifetime, recovering and recycling resources and minimising the quantity going to landfill; and
- Setting limitations to exploration and mining in specific areas to conserve natural habitats.

Part II: Resource efficiency and sustainable alternatives (substitutes)

Although the workshop participants noted that unlimited material substitution is unlikely, due to some materials not being amenable to it (e.g. phosphorous), substitution was still recognised as one of the ways of dealing with material criticality. The main issues associated with substitution are:

- There is a need to use a broader concept for substitution, beyond the substitution of a single material. We need to think in terms of whole process substitution (such as the examples given in the International Synergies Limited presentation on the National Industrial Symbiosis Programme) and possibly changes to business models.
- It is important to realise that substitution might in fact lead to new resource security issues, resulting from the increased demand for the newly substituted material.
- Examples exist of producing some of the critical materials from sustainable sources and processes.

Part III: Cost efficient and innovative recycling

Metal recycling, particularly for critical metals, makes good economic sense since there is no downgrading of the metals and no loss of monetary value, no need to incentivise industry to choose recycled metal over virgin sources and it is theoretically readily available in our end of life products. Nonetheless, recycling rates of critical metals remains very low and this is due to the fact that recycling of these resources requires a system approach. Workshop presentations and discussion identified the following challenges with regards to recycling:

- In order to increase recycling rates, collection rates have to increase. This will require the design of a smarter collection system as well as the incentivisation of consumers to deposit their EoL product stocks (e.g. old mobile phones).
- The quality of the recycled materials has to be improved through reducing downgrading and ensuring that materials remain in the supply chain. This would require overcoming technological challenges around dismantling, pre-processing and metallurgy.
- Recycling has to be made more efficient and innovative to recover critical materials from new types of waste.
- The development of new recycling technologies and skills can lead to the creation of jobs and growth for developed countries.
- The entire lifecycle must be optimised to minimise losses. This includes tackling illegal recycling and illegal exports of waste products.
- Other challenges include improving value added, setting standards, creating legislative support and managing materials cycle.

Part IV: Reducing waste in production and design

This section deals with issues of resource efficiency, product life extension strategies and sustainable design. Although workshop participants recognise resource efficiency as making sound economic sense, it is clear that the business case for resource efficiency is not always made. Therefore, the main challenge will be to change perceptions and to try to engage businesses, mainly SMEs. Government procurement policies can help promote resource efficiency. With regards to remanufacturing and reuse of products (i.e. extending product lifetimes), two main challenges were identified: the need to move away from volume driven business models and the need to change consumer behaviours and perception about remanufactured and reused products. Product design is critical to the sustainability of a product and therefore product designers need to be made aware of the resource implications of their design and their overall attitude needs to change to take into account sustainability issues.

The workshop also identified a number of cross-cutting issues, the first of which relates to information and data. Overall, participants thought that there are some knowledge gaps that must be filled, including a better understanding of resources, reserves and stocks as well as better exploration of the potential for metal in Europe, more accurate predictions of supply and demand and the need for business and sector specific analysis of criticality. There is also the need to change business models and take a systems approach to rare resources. The third issue had to do with standardisation and the need to design standards for criticality, sustainable sourcing and resource efficiency as well as the need to standardise warranty policy for re-manufactured and reused goods, in order to increase customer by-in. The need for a regulatory framework that would promote resource efficiency (by, for example, preventing illegal waste exports), the need for skilled personnel and the need to change overall customer behaviours with regards to products and resource efficiency were other cross-cutting issues.

4.7 U.S. Research

This section summarises two reports relating to resource security in the U.S. The first one is jointly produced by the American Physical Society (APS) and the Materials Research Society (MRS) and provides a list of recommendations for securing critical materials supply for the U.S. The second report comes from California Institute of Technology’s Resnick Institute and again offers views on how to address the issue of resource security, but by addressing demand and supply issues separately.

4.7.1 APS/MRS

In April 2010 a workshop of an exploratory nature, organised by MIT's Energy Initiative (MITEI) together with the American Physical Society's Panel on Public Affairs and the Materials Research Society, brought together experts in the area of critical materials for new energy technologies (APS/MRS, 2011). The workshop served as a kickoff for an APS/MRS study published in February 2011. Since the U.S. depends on imports for more than 90% of most of the energy critical materials, this study discusses the availability of these materials.

The report begins by outlining what it is that makes these materials critical from a resource security point of view i.e. crustal abundance and distribution, geopolitical risks, the risk of joint production, environmental and social concerns and response times in production and utilisation. The report then quickly moves into the following list of recommendations for the U.S. government:

- Information should be regularly gathered and disseminated to cover: potential resources, production, scrap generation, inventories of old scrap, basic applications research, product design, manufacturing, use and disposal of products containing energy critical elements, and potential for recycling.
- The government should regularly survey potential energy technologies and supply chain for elements to identify critical applications and potential shortfalls.
- R&D effort should be focussed on energy critical elements and substitutes to cover mining, extraction, manufacturing, geological deposit modelling, characterisation and substitution, recycling and lifecycle assessments.
- The government should provide support for training of undergraduate, graduate and post doctoral students in the areas of critical elements.
- Efficient material use should be promoted through: recycling, improved extraction technology, reduced concentration in applications, replacement in non-critical applications, development of substitutes in critical applications and lifestyle adaptations.
- The government should establish certification requirements for energy critical element-related products to cover minimisation of concerns related to scarcity and toxicity, the ease of disassembly, the availability of appropriate recycling technology and the potential for functional recycling.
- The rates of post-consumer collection of energy critical elements should be improved.

The report also suggests that the U.S. government should start stockpiling helium again (in addition to that needed for military applications) as it is indispensable in cryogenic applications and advanced nuclear reactor design. If helium is not captured during its extraction, as a co-product of natural gas, it escapes into the atmosphere and is practically lost. Therefore, there is a real case to be made for its stockpiling, given that overall demand for He has been steadily increasing and will likely continue to do so.

With the exception of He, the report does not recommend other government stockpiles because they can have unintended and disruptive effects on markets and can be disincentives for innovation.

4.7.2 Resnick Institute

In 2011, Caltech's Resnick Institute, which specialises in energy science and technology, published its report 'Critical Materials for Sustainable Energy Applications' (Resnick Institute, 2011). In this report the Institute summarises the information provided by criticality assessments (mainly the U.S. 2010 DOE report, the Europe EU14 report and the APS/MRS report) to give an overview of which materials are considered to be critical. The only addition the Resnick Institute report makes to the critical materials list is silver (Ag). This is because, in 2010, 8.6% of the mined Ag went into photovoltaic panel production and in 2011 the price of Ag increased, accounting for about 5% of panel cost. It is predicted that in 2015 Ag use in photovoltaic panels will account for 25% of 2010 Ag production.

The report proposes the implementation of an R&D strategy which will address both the demand and supply sides of the problem, at the same time recognising that there is no one-size-fits-all solution and that each industry, technology and element must eventually be evaluated individually. The supply and demand side solutions offered by the authors, and a short discussion of each, appear in greater detail below.

Supply side improvements:

- Sourcing strategies such as diversification, hedging, stockpiling and buying materials in bulk. But these are not expected to provide a long term solution.
- Discover and develop new deposits: metal supply is limited therefore this is neither sustainable nor sufficient. It is also very costly to extract materials. For most co-produced metals increasing demand will not provide a strong enough economic incentive to mine the base metal. The only exception is REEs whose main metal is cerium (Ce). Increasing demand for Ce will make mining of other REEs more economically favourable
- Improve process yields: identify troublesome bottlenecks and improve efficiency.

The biggest difficulty is the variability from material to material and even from ore to ore. This is where a lack of scientific expertise becomes evident. China is funding a national research lab focussing on improving the yield of REEs. Similar initiatives might help other countries.

- Reduce waste and increase EoL recycling: this can have a significant impact. Japan has greatly increased its recycling of indium from scrap, even though it currently does so at an economic loss. However, new business models are required to encourage this practice, particularly in the consumer-market sector where open loop recycling is used. Nonetheless, recycling alone will not be able to cover demand.

Demand side improvements:

- The greatest reduction in demand will most likely come from R&D: designing products for ease of recycling and reuse, designing new materials to minimise the use of at-risk elements, finding alternative material substitutions and substituting entire systems where appropriate to reduce or eliminate use of critical metals.
- Improvements in manufacturing, waste reduction and scrap recycling could lead to 5-20% savings in critical material use.
- Detailed optimisation of the material/component used might lead to similar savings.
- Substituting with less critical materials could lead to 20-80% decrease in critical material use.
- Full scale system substitutions could lead to 80-100% reduction in critical material use.

Finally, the report provides two case studies on how critical material use could be reduced in solar/photovoltaic applications and in permanent magnets.

4.8 UK Research

The issue of resource security has been the focal point for a lot of research in the UK, ranging from desk studies to identify critical materials for businesses to specific research at universities on particular applications of certain materials in green technologies. This section aims to summarise some of this research.

4.8.1 British Geological Survey

The British Geological Survey published its Risk List 2011 for critical materials, carrying out its assessment based on scarcity, production concentration, reserve base distribution and governance indicators (BGS, 2011). At the top of the list a number of elements or element groups that are included in the EU14 critical list can be found. According to the BGS Risk List 2011, antimony, PGMs, mercury, tungsten, REEs, and niobium are the elements associated with the highest risk.

The list focuses on risks to supply and does not consider any factors that influence demand (e.g. criticality of an element for specific technologies) or how easy it is to substitute that element with another. It is a relatively simplistic approach as many factors considered in other criticality assessments (such as environment) are not considered here. Nonetheless, it adds to the amount of information available on these elements. A noteworthy point made in the Risk List is that the minerals markets are not static; new reserves are continually added in response to drivers such as demand and advances in technology, therefore there is a need to re-examine criticality lists regularly.

4.8.2 Resource Efficiency KTN

An early report on resource security for the UK was commissioned by the Resource Efficiency Knowledge Transfer Network (Morley and Etherly, 2008). This report begins by exploring existing literature to consider whether the market on its own will be able to solve any issues of material security and finds that, in general, market forces alone will not be enough.

In the short-term, if prices for materials are high enough, market forces will encourage new capacity, perhaps in the form of increasing material recycling or developing technological innovations that either use less material or substitute with another material. However, there is likely to be a lag time between establishing production and obtaining product approvals from customers. This might in turn cause economic disruptions in materials that have no substitutes. Furthermore, since at the moment the environmental and climate change impacts of mining activities are not factored into the mining costs, the mining industry has no market incentive to minimise its environmental footprint. If anything, eventual shortages of materials are likely to cause an increase in the industry's environmental impact as reserves of lower quality are mined. Therefore, it is more likely that pressure from society will be what causes improvements in the industry's impact and not the market itself.

The authors used eight criteria to rank 69 elements and minerals in order of their criticality. Two types of criteria were used, 'material risk' criteria and 'supply risk' criteria. The material risk criteria were global consumption levels, lack of substitutability, global warming potential and total material requirement; whereas the supply-risk criteria were scarcity, monopoly supply, political instability in key supplying regions and vulnerability to the effect of climate change in key supplying regions. This analysis resulted in a list of eight most insecure materials, which includes some of the world's most valuable metals. Almost all of these eight materials come from regions with high political instability and high vulnerability to the effects of climate change. In decreasing order of insecurity the materials are: gold, rhodium, platinum, strontium, silver, antimony and tin. Interestingly, if the supply risks and material risks were considered separately, different materials appeared at the top of the list.

There are a number of resource efficiency measures that could be taken to ensure material security for the future and the authors provide some key examples where work is already taking place. It is possible to substitute some of the insecure materials with more available ones, and although technological developments such as this can take years, work is already underway for some materials, particularly with the increasing role of nanotechnology. For example, researchers at the Tokyo Institute of Technology have successfully modified aluminium oxide to be used instead of indium tin oxide in LCD televisions. Work in minimising material use is also taking place, an example being the work done by Oxford Catalysts in eliminating promoters such as platinum, ruthenium and rhenium from catalysts. Closed-loop recycling of materials is another way to improve resource efficiency and various initiatives are already taking place to recover metals such as PGMs, cobalt and neodymium from catalytic converters, batteries and magnets respectively. Finally, the collection of dispersed residuals from the environment is another route to material security. This could take the form of ‘urban mining.’ However, the authors note that such strategies should take a whole lifecycle approach and factor in the impacts of collection and reprocessing.

The report concludes with a number of recommendations falling into three groups:

Recommendations for policy makers:

- Environmental impacts should be incorporated into the costs of mining and metal production companies.
- Provide assistance to developing countries with regards to environmental and social regulation of industries.
- Adopt policies that encourage aggregation of insecure materials, while taking a whole lifecycle approach of impacts.
- Maximise recycling and recovery rates of metals that show greatest environmental benefits.

Recommendations for businesses:

- Promote products that are sustainably mined and produced.
- Incorporate environmental externalities through voluntary codes and agreements.
- Design products that encourage easier recovery and discourage dispersal of materials.

- Adopt lifecycle management policies.

Recommendations for innovation funders:

- Encourage projects that develop substitutes for insecure materials, paying particular attention to nanotechnology projects.
- Encourage technologies that enable ‘mining’ of waste streams.
- Stimulate sustainable product design that considers lifecycle issues.
- Take account of displacement effects when funding green technologies.

4.8.3 Defra SCP

Various government departments have also commissioned research into the issue of resource security. Defra’s Sustainable Consumption and Production (SCP) team commissioned research to determine what the risks are for businesses and how they can overcome them (Defra, 2010). This study sought to identify those at-risk resources that are essential to UK businesses and determine what businesses can do to overcome the issue of resource security and ensure that their operations remain sustainable and profitable. The study looked at both biotic and non-biotic resources and used literature sources and stakeholder comments to identify those that are particularly important.

The report showed that, although in the short term demand and supply for a number of resources will decrease as a result of the current economic climate, overall resource demand is likely to increase in the medium to long term. Specifically, the following resources and sectors using them were considered to be particularly at risk: aggregates used in construction and civil engineering, fish, indium used in electronics, IT and renewable energy sector, lithium used in the automotive and battery industries, phosphorus used in agriculture and rare earth elements used in the automotive, chemical, engineering and renewable energy sectors.

However, the report also highlights that these resource risks do not necessarily have to be detrimental for businesses but could actually present opportunities and benefits, in the sense that there will be opportunities for development of alternative markets and new material sources through the mining of previously unexploited deposits. Furthermore, the recycling industry is likely to see a boom with the development of new collection and treatment infrastructure and markets. There will also be opportunities in the research and development field as there will be the need for substitute materials and technologies as well as the need for eco-design. To further illustrate this point, the study developed a series of case studies.

Finally, the study offers some conclusions and recommendations for further activities:

- There is a need to engage with SMEs and raise awareness about the issue of resource security for their businesses.
- The flow of information on resource risks needs to be improved to allow businesses and policy makers to make informed decisions.
- Businesses need to understand their supply chains because even if they do not use any at-risk resources others downstream or upstream in their supply chain might and this could have an effect on them.
- There are real opportunities for businesses in the form of product reuse, remanufacture and recycling.
- Some sector stakeholders are eager to have more interaction with government over issues of resource security.
- The situation regarding resource security is dynamic therefore there is a need to keep an eye on developments

4.8.4 DfT and BIS

The Departments for Transport (DfT) and for Business, Innovation and Skills (BIS) commissioned more specific research looking at lanthanide (rare earth) resources and alternatives, focussing on their use in permanent magnets and batteries in low carbon vehicles and wind turbines (Oakdene Hollins, 2010). The report begins by describing why rare earths are important and continues on to give an account of rare earth reserves around the world, most of which are found in China, Australia, Canada, the U.S. and to a smaller extent in other countries. Small reserves are also found in the UK in the tailings of some disused tin mines in Cornwall but at the moment they cannot be economically recovered. A detailed account of the mines/companies in each of these countries that are responsible for the world’s supply of lanthanides is also given.

The study tries to predict the growth of the hybrid and electric vehicle and wind turbine markets into 2014 and assess the implications of this growth on the demand for rare earths. Demand is forecasted to grow at 8-11% per year between 2011 and 2014. The highest growth is expected for magnets and metal alloys, as required in hybrid and electric vehicles. Hybrids are expected to gain an increasing market share, but other applications such as wind turbines will compete for the essential materials. Since total world demand is forecast to exceed total world supply, shortages are expected for key heavy elements such as dysprosium and terbium. According to the study, supply of neodymium will be a limiting factor for the penetration of rare earth magnet-based generator wind turbines for energy generation unless there is very strong growth in the long term supply of rare earths.

The study goes on to investigate alternative technologies for magnets and batteries. The results show that demand for rare earths in batteries will decline as the industry is moving away from nickel metal hydride (NiMH) batteries and into lithium-based technology, but this in turn could cause supply issues with lithium. A number of different battery technologies are being investigated which are not heavily reliant on rare earths, and although the UK has strong research in this area it probably does not have the manufacturing base to exploit developments in a commercial setting.

Options for alternative technologies which eliminate or reduce the quantity of rare earths in electric vehicle motor magnets are limited. Any reduction is likely to be achieved through the minimisation of rare earths usage in existing magnetic materials, or through the adoption of entirely new varieties of electric motor. Meanwhile a large number of alternative energy storage options are being researched. Many of these are a long way off commercial application, but lithium-based batteries are already a viable alternative to current NiMH batteries for hybrid vehicles.

Rare earths used in batteries are currently not recovered, although there is an indication that existing players might consider this. While recovery processes relevant to rare earths are available, none of them is currently commercially viable. Japan is leading the research into recycling options, although there has been very limited research activity in recent years.

The report also assessed the environmental impact of rare earths and found that impacts differ depending on demand. Impacts may appear high per kilogram of production but when used in an application the impacts relative to that of the whole product are generally not substantial.

Finally, a number of recommendations are made which mainly focus on improving the recycling infrastructure for rare earths and developing academic and industrial collaboration for research in magnet development with partners that are already established in the field (i.e. Europe, USA and Japan). The report also calls for transparency throughout the supply chain as well as encouraging China to maintain consistency in its long-term strategy in rare earths, as this will improve the certainty of the investment planning landscape.

4.8.5 European Pathway to Zero Waste

Another report, published for the European Pathway to Zero Waste, focuses specifically on the South East of England (Oakdene Hollins, 2011). It examines the application of the EU14 critical materials and tries to identify measures that can be taken to protect and recover them.

The report provides useful information on supply and supplying countries for these materials, on forecasted demand growth per year, on their price and on their major applications. All this is usefully summarised in Table 10, from which it can be seen that for 7 of the critical materials a single application accounts for over half of the consumption and several materials are used in more than one application.

These 14 materials were then screened based on consumption levels, economic value and carbon impact, and twelve markets were selected for further investigation. Each of the applications (40 in total) within these markets was studied in detail to assess existing supply chains, current EoL practice, and to assess potential for reducing critical raw material demand through improved recovery. This resulted in the identification of 10 applications as having high potential for recovery (Table 11) and 11 as having medium potential. Catalytic converters have the highest potential market value for recovery, even if it is assumed that over half of them are already recovered, whereas tantalum in aerospace superalloys and beryllium used in landing gear show low potential recovery values. The assessment shows that most of these opportunities are likely to be feasible in the short term.

The study also shows that pre-consumer recycling is efficient for almost all the critical materials and often accounts for a large proportion of overall supply, whereas post-consumer recycling is very variable and often falls outside of common recycling activities. Whilst recovery and recycling can have an impact on demand, other measures such as substitution, reuse or elimination may be necessary to reduce demand in the future.

The report also finds that the technology for recycling almost all the 14 critical materials is available, at least at a demonstration level. However, other factors such as lack of product collection, dispersion of critical materials in many products, difficulties in separating out the critical materials from products and uncertainties related to future quantities and qualities of materials limit their recycling.

Nonetheless, when considering existing and future uses of critical materials, the following high potential opportunities for increased recovery were identified:

- Well established but have further potential: catalysts (catalytic converters), packaging (beverage cans).
- Will require implementation of new infrastructure technology: aerospace (superalloys, landing gear, aluminium alloys), batteries (portable Li-ion), electronics and ICT (hard disk drive magnets and layers).
- Future prospect: Electronics and ICT (LCD screens), electrical equipment (wind turbine magnets).

Finally, the report concludes with a list of recommendations to improve material security. These include improvements in collection and sorting techniques, implementation of new technology for the recovery of critical materials from waste products, and design for disassembly. The study also recommends that there should be some linking of the designers and producers of products with the waste management companies so they can better understand the issues they face when it comes to recovery and recycling. At the policy level, the study recommends more sophisticated waste recovery targets that are not based on weight, and alignment and enforcement of regulations to provide recyclers with greater certainty over future waste streams.

Critical Raw Material	World Supply 2009 (tonnes)*	Primary Producing Countries (%)	Major Applications (%)	Forecast Demand Growth p.a. (%)	Price – 3yr Ave ($/kg)
Antimony	187,000	China (91%) Bolivia (2%) Russia (2%)	Flame retardants (72%) Batteries (19%) Glass (9%)	4.2%	$6.58
Beryllium	140	United States (86%) China (14%) Mozambique (1%)	Electronics/it (20%) Electric equipment (20%) Final consumer goods (15%)	3.0%	$165
Cobalt	62,000	Congo Kinshasa (40%) Australia (10%) China (10%)	Batteries (25%) Superalloys (22%) Carbides/tooling (12%)	2.5%	$57.45
Fluorspar	5,100,000	China (59%) Mexico (18%) Mongolia (5%)	Hydrogen fluoride (60%) Steel (20%) Aluminium (12%)	3.4%	$0.42
Gallium	118	China (32%) Germany (19%) Kazakhstan (14%)	Integrated circuits (66%) Laser diodes & led (18%) R&D (14%)	10.2%	$499
Germanium	140	China (71%) Russia (4%) United States (3%)	Fibre optic (30%) Infrared optics (25%) Catalyst polymers (25%)	3.4%	$1,151
Graphite	1,130,000	China (71%) India (12%) Brazil (7%)	Foundries (24%) Steel industry (24%) Crucible production (15%)	3.0%	$1.16
Indium	1,200	China (50%) South Korea (14%) Japan (10%)	Flat panel displays (74%) Other ito (10%) Low melting point alloys (10%)	6.5%	$506

Magnesium	760,000	China (77%) United States (7%) Russia (5%)	Casting alloys (50%) Packaging (16%) Desulfurization (15%)	7.3%	$3.29
Niobium	62,000	Brazil (92%) Canada (7%) Others (1%)	Structural (31%) Automotive (28%) Pipeline (24%)	10.1%	$62.05
Platinum group metals	445	South Africa (61%) Russia (25%) Canada (4%)	Autocatalysts (53%) Jewellery (20%) Electronics/electrics (11%)	2.7%	$31,847
Rare earth elements	124,000	China (97%) India (2%) Brazil (1%)	Catalysts (20%) Magnets (19%) Glass (12%)	9.8%	$29.83
Tantalum	1,160	Australia (48%) Brazil (16%) Congo Kinshasa (9%)	Metal powder (40%) Superalloys (15%) Tantalum carbide (10%)	5.3%	$352
Tungsten	94,009	China (81%) Russia (4%) Canada (3%)	Cemented carbides (60%) Fabricated products (17%) Alloy steels (13%)	4.9%	$41.21

Table 10 Summary information on production, application, demand and cost for the EU14 critical materials (Oakdene Hollins, 2011)

Market/ Submarket	Application	Raw Material(s)	Current Total Consumption (tonnes)	Current Total Consumption ($ millions)	Estimated Carbon Impact	Timeframe
Aerospace	Superalloys	Cobalt	10,639	611	N/A	Short
		Niobium	4,960	308		Short
		Tantalum	58	20		Short
	Landing gear	Beryllium	21	3	N/A	Short
	Aluminium alloys	Magnesium	54,900	180	Medium	Short
Portable Batteries	Li-ion	Cobalt	11,594	666	Medium	Short
		Graphite	39,776	46		Short
Catalytic Converters (PGMs)	Vehicles	PGMs	232	7,398	Low	Short
Wind Turbines	Wind turbines	REEs	6,126	183	Medium	Long
Screens	Used as ITO in LCD screens	Indium	444	225	Low	Medium
Hard Disk Drives	80% of ruthenium produced in used in hard drives	PGM (ruthenium)	10	327	Medium	Short
	Neodymium is used in magnets for HDD	REEs	7,304	218	Medium	Short
Beverage Cans	Aluminium alloys	Magnesium	97,600	321	High	Short

Table 11 Ten high recovery potential applications and the critical materials they use (Oakdene Hollins, 2011)

4.8.6 House of Commons

The House of Commons Science and Technology Committee launched an inquiry into strategically important metals in late 2010 by requesting written evidence and holding oral evidence sessions with representatives from the government, industry, academia and trade bodies to gauge their opinions with regards to the vulnerability of the UK economy to supply risks for these critical materials, and issues around recycling, reuse, substitution, domestic extraction and production, and environmental concerns (House of Commons, 2011).

The report outlines the opinions of the respondents and provides supporting data from recent studies, where available. In addition to arriving to a set of conclusions with regards to critical materials this House of Commons report also outlines a number of recommendations for future government action. The full set of conclusions and recommendations are available in the report, and the most pertinent ones are summarised below:

1. There is some disagreement between respondents over the UK's vulnerability to metal shortages. However, although the UK is not considered as vulnerable as countries that use the metals directly, such as Japan and the USA, some industries in the UK are dependent on a range of metals at stable prices, and the green economy depends on these metals as well. Therefore, it is no surprise that UK companies would mostly like to know which metals will be critical in the future. The repost recommends that the Government clarifies which departments are responsible for critical metals. The suggestion to create a database of critical metal information is supported. Furthermore, it is recommended that the Government ensures that future changes in supply and prices do not disproportionally affect SMEs, by ensuring that SMEs are aware of the issues and are prepared for any future changes.

2. Global demand for strategic metals will continue to increase due to demand from emerging economies and new technologies with associated effects on price and availability. Therefore, to better understand potential risks to supply, future demand needs to be assessed. Furthermore, the report calls for the Government to investigate the effects of speculation on price and supply volatility, and through discussion and collaboration with international forums to address the issue of market distortions caused by restrictions in free trade.

3. In addition to metals, helium and phosphorus were considered important materials.

4. Most respondents agree that reserves are unlikely to run out over the coming decades, since an increase in demand will make the exploitation of lower grade reserves a more economically viable option. Although this would provide an

opportunity for developing nations, it could also lead to significant environmental, social and monetary costs. Therefore the UK Government is encouraged to work with the International Monetary Fund and OECD to ensure that the social and environmental impacts of mining in developing countries are minimised.

5. With regards to metal efficiency, the report concludes that a cradle-to-cradle approach must be taken, with intelligent product design and communication between manufactures, designers and waste processors, being key tools for the success of the approach. According to the report the Government should encourage the incorporation of sustainable design thinking in manufacturing and waste processing as well as support and encourage labelling schemes to trace metals from the mine to the market.

6. Overall, the report finds that there is a lack of information regarding the extent to which recycling of metals can meet the UK metal demand, and although 90% of metals by weight are recycled in the UK, some critical metals are likely to be lost in the 10% not recycled. Therefore, it is recommended that the Government conducts a review of metal resources in the UK to estimate the market value of these resources and the movement in and out of the UK. Additionally, work to identify ways to improve WEEE collection and collaboration with the EU to extend WEEE regulations to cover industrial and commercial waste should continue. The export of metal waste should also be minimised, but where exporting cannot be avoided, to work with other governments to ensure that environmental standards are upheld.

7. Finally, the report explores the issue of domestic deposits of metals and concludes that the domestic mining could alleviate some of the supply risks for UK businesses since the UK has unexploited deposits of various critical metals (although it is not clear whether extraction is economically viable). It is likely that domestic mining will have some environmental impact, but this will most likely be lower than that of overseas mining. In addition to mining, research is also taking place to determine whether metals can be extracted from industrial waste streams. Therefore, the Government is encouraged to work with BGS to gain a better understanding of potentially valuable domestic resources, to ensure that regulations do not unnecessarily restrict the use of reserves in industrial waste streams, to invest in the necessary research to ensure that domestic mining will have the lowest possible environmental impact and to ensure that the planning process does not unnecessarily delay mining projects.

4.8.7 Green Alliance

Green Alliance has recently published a report on resource security, which tries to promote the use of a circular economy when it comes to resource use (rather than the current linear use of resources) as a means of avoiding some of the impacts of resource extraction as well as the impacts associated with waste production (Hislop and Hill, 2011). In so doing it looks at how the concept of a circular economy can be applied to three important resources for the UK economy: metals, phosphorus and water.

Green Alliance defines a circular economy as ‘one where waste is designed out, through addressing the nature of products and their supply chains. This involves improving or changing extraction and production processes. It means ensuring that consumers are able and encouraged to buy products that are more durable, as well as reducing consumption where possible. Products are able to be easily and economically repaired, upgraded or remanufactured. They are also designed for recycling and recovery through convenient and intuitive collection systems.’

According to Green Alliance, the way to promote such a circular economy is through the use of economic instruments, such as the introduction, or removal if appropriate, of taxes and subsidies, as well as the use of deposit refunds and trading schemes for which the price is set either directly or indirectly by legislation. At the same time, sustainable sourcing of these resources needs to be promoted through the introduction of stewardship schemes. In contrast to current schemes, which cause an increase in the price we pay for the certified products, Green Alliance suggests that in the future uncertified products can be charged more and as a result priced out of the market.

This section summarises the recommendations with regards to metals and phosphorus but the recommendations regarding water are also shown in Table 12.

Summary of recommendations	
Metals	Product standards that embody design for durability, recovery and recycling, with the addition of a product levy, to help give preference to such products in the market place as well as potentially funding the development of good recycling infrastructure. A recovery reward to drive higher rates of return to ensure that products can be reprocessed and valuable resources reclaimed. Better life cycle analysis to inform the choice of substitutes for some materials, which could also be promoted through a product levy.
Phosphorus	A range of incentives to encourage the recovery of more secondary phosphate from sewage and the use of high quality, secondary sources of phosphate in agriculture. Examination of a phosphate levy, not just because this might help to ensure careful use of the product, but also to raise money for phosphate recovery and recycling.
Water	Universal metering, more effective tariffs for consumers, and abstraction charging that reflects scarcity. Increase awareness of embedded water in the goods we buy, whether from home or abroad, by promoting water stewardship and by encouraging greater transparency from companies. Make water stewardship part of an approach that sets environmental standards for products.
Resource Stewardship	The development of the 'circular economy plus' where extraction of all raw materials, both renewable and non-renewable, as well as water and energy production, are achieved under a flexible but powerful ethos of stewardship by companies.

Table 12 Green Alliance recommendations to promote a circular economy (Hislop and Hill, 2011)

With regards to metals, the report highlights their importance to specific technologies. It also highlights that most metals have quite low recycling rates as it can be cheaper to procure new metals than to recover and reprocess old scrap. Additionally, some metals are so dispersed that it becomes difficult to recover them at the required purity. What is more, materials leak from the system through exports to countries with sub-standard recycling rates.

The report offers potential policy solutions to help address the issue of metal security. These are grouped into 6 categories:

1. Improving collection rates and incentives for recovery.

   While recognising the importance of the European directives on WEEE, end of life vehicle (ELV), packaging and batteries, the study suggests that there is more that can be done. Specifically, it suggests that the WEEE and batteries directives lack ambition as higher targets could be set, whereas with regards to the packaging directive higher recovery rates for aluminium and steel could be achieved through better collection systems, on the go recycling and deposit refund schemes. The study also highlights some of the issues surrounding the ELV directive, specifically the lack of requirements in the legislation for separating out some key metals from car components. Modern cars contain a number of materials termed critical by various studies, enclosed in mp3 players, navigators and small electronic motors for seats for example. These are lost through open loop recycling.

2. Recycling targets that focus on specific materials and their quality, rather than simply on tonnages.

   Since current targets are weight-based, there is no incentive to recover specialist metals, which are the ones that are termed ‘critical’ and are of economic and environmental interest.

3. Design for disassembly and recycling.

   Good design will allow the accessibility to important components and remove hazardous substances that could prevent recycling. A system of individual producer responsibility, rather than the collective one currently required by the WEEE Directive, could incentivise this.

4. Encouraging longer product life.

   There are a few ways of doing this, for example through ‘product service systems’, product standards, extended product warranties and designing products to make repairs easier. However, the success of all of these depends on a change in consumer behaviour and values.

5. Avoiding leakage of valuable materials through exports.

The study reports that 60% of the UK’s metal is exported, either legally or illegally. This requires further examination to decide whether some materials should remain within the UK for recovery and recycling.

6. Solutions based on economic instruments.

   Three economic instruments are proposed in this study:
   - a ‘recovery reward’ on electronic products, which could take the form of a deposit refund scheme, or a scheme where householders are rewarded for the electronic appliances that they put out for recycling;
   - the use of product standards in combination with economic instruments to incentivise better product design, potentially through levies or setting criteria for product design that would not only promote characteristics such as ease of recycling but also avoid use of toxic or harmful substances; and
   - incentivising the substitution of specific materials, potentially through levies that could be introduced on materials that use toxic or harmful substances, for example. However, the report suggests that before this can be done, the environmental trade-offs must be completely understood and this will require more comprehensive lifecycle analysis.

Phosphorus is also discussed in the report as a non-renewable but very important resource as it is essential for crop production. As more food is required to feed the world’s increasing population, an increasing amount of phosphorus is also required. The world’s largest phosphorus rock reserves are concentrated in Morocco, Western Sahara and China, but China and the U.S. have imposed export restrictions in recent years. As the world’s high quality phosphorus rock reserves become depleted (or restricted) we are forced to use low quality reserves at the expense of using more energy and water to extract the phosphorus. All these factors combined result in very high prices for this necessary element.

A more circular economy that focuses on reuse and recycling of phosphate could not only help address some of these problems but could also help address the issue of downstream water pollution arising from the washing off of phosphorus from land to water courses. The study suggests three main areas that can help do that:

- Reduction in demand through the use of more sustainable practices in farming and agriculture but also through more sustainable living practices overall such as reducing food waste and adopting a lower impact diet;

- Reuse of secondary sources. This already takes place in the UK with about 65% of sludge recycled to farmland, but European levels overall are lower than that. However, this would require more research to ensure that all the phosphorus added to land is in a form that can be utilised by the crops; and

- Recovery of phosphate through recycling of sewage, animal manure and industrial waste. However, there are economic, technological and systematic obstacles that must be addressed first.

Additionally the study recommends three economic approaches to securing phosphate supply:

- Incentives to reduce demand for mineral phosphorus, possibly through taxes on products that are phosphorus-intensive, such as meat or dairy. However, these have to be carefully studied to ensure that World Trade Organisation rules are not infringed and that farmers and the UK industry in general are not penalised;

- Incentives for more direct use of good quality secondary nutrients, which could include more incentives to promote anaerobic digestion as a source of phosphorus-rich soil enhancer and recycling credits for good quality secondary nutrients; and

- Incentivising the recovery of more phosphorus from sewage through the use of product standards in combination with economic instruments

4.8.8 Research Councils UK

The RCUK's Global Uncertainties programme 'brings together the activities of the UK Research Councils in response to global security challenges. The programme will help governments, businesses and societies to better predict, detect, prevent and mitigate threats to security'[8].

Competition for resources is a second-tier theme under the Research Councils UK (RCUK) Global Uncertainties programme, which addresses a range of issues falling into three categories:

1. Geopolitics of competition for resources and conflicts

   This involves a number of projects exploring how the relationships between countries and regions are affected when there is competition for resources. An example of the type of work that falls within this category is the project 'Where Empires Meet: The Border Economies of Russia, China and Mongolia', carried out by the University of Cambridge.

2. Economies, sustainability of resources and waste

   This covers work to study the dynamics of supply, the demand for energy and minerals and how policies, initiatives and behaviour affect their sustainability.

[8] http://www.globaluncertainties.org.uk/

Energy systems are mainly studied by the Sussex Energy Group whereas the Minerals and Waste programme under the British Geological Survey carries out applied research on the security of supply of UK mineral resources, providing up-to-date spatial, technical and statistical information on minerals.

3. Urban sustainability

   These projects explore how resource sustainability can be achieved in urban environments that are becoming increasingly densely populated. Examples of projects include those looking at urban design and at greater resource conservation coupled with more efficient use of resources

The work done by the Global Uncertainties programme is also closely related to and complemented by work carried out under other programmes such as Living with Environmental Change and Energy.

4.8.9 Applied Research at UK Universities

In addition to desk based research on resource security, more applied research is taking place at UK industry and universities. Some of this research was presented at the Sustainable Materials for Emerging Energy Technologies (SMEET) conference organised by the Energy Materials Group at the Institute of Materials, Minerals and Mining (IOM3, 2011).

The conference, which took place in London on 28 February 2011, included nine presentations, from industry and academia, covering a range of materials used in emerging energy technologies, as well as a range of issues ranging from risks to supply to material demand for particular applications.

Researchers at Northumbria University are working with cadmium telluride (CdTe) thin film photovoltaics and are focussing on maximising the use of materials by reducing the thickness of the devices while maintaining or increasing their performance. They are also working on developing emerging materials that will replace costly and scarce materials such as gallium and indium. Another example from the University of Strathclyde in Glasgow presented research taking place using lithium oxygen batteries and super capacitors in electric cars to overcome limits to speed and acceleration. The super capacitors also help reduce the amount of on-board battery storage and thus help use less critical materials. The University of Nottingham offers another example of research that has the potential to reduce demand for certain elements, this time through development of hydrogen storage technology.

Any UK university that has a materials department is in all likelihood carrying out research that will have an impact on clean energy technologies and thus perhaps on the use of critical materials. In addition to the university work presented at the SMEET conference, three other UK universities are doing important research in this area.

1. University of Birmingham

   At the University of Birmingham’s School of Metallurgy and Materials, research is taking place on the corrosion protection, extraction and recycling of rare earth magnets. Projects are also taking place in the area of hydrogen storage[9].

2. Bath University

   The Materials Chemistry Group at Bath University is researching lithium battery materials for rechargeable batteries, fuel cell materials and inorganic materials for solar cells which do not include indium[10].

3. University of Cambridge

   Research at the University of Cambridge's Department of Materials Sciences and Metallurgy is split into five research themes: device materials, electron microscopy, materials chemistry, medical & pharmaceutical, and structural materials. In addition to these five themes the Department carries out research in the areas of clean energy and sustainability, and nuclear energy. Work under the clean energy and sustainability research initiative looks at clean energy production (including new materials and structures for solar cells, energy storage and fuel cells), reducing energy production (including through innovative processing for energy-efficient materials extraction, solid-state lighting to reduce electricity consumption) and recycling and clean processing[11].

[9] http://www.birmingham.ac.uk/staff/profiles/metallurgy/walton-allan.aspx
[10] http://people.bath.ac.uk/msi20/themes.shtml#libatteries
[11] http://www.msm.cam.ac.uk/research/themes.php

5. Reports on Resource Efficiency

Resource efficiency is one of the ways ensuring the sustainable use of resources and thus resource security. Therefore, it is no surprise that many reports that discuss resource efficiency also discuss or at least touch on the issue of resource security. This section summarises a few of these reports, chosen because of their relevance but also because of their recent publication date.

5.1 European Environment Agency Survey on Resource Efficiency

This survey, carried out by the European Environment Agency (EEA) and its European Topic Centre on Sustainable Consumption and Production (ETC/SCP), aimed to collect, analyse and disseminate information about resource efficiency policies in European countries and to facilitate sharing of experiences and good practice (EEA, 2011). A total of 31 countries returned responses to the survey, including 25 of the EU27. In addition to the information presented in this report, the EEA also published shorter profiles for the 31 countries.

The key points from the analysis of the countries' responses are:

- There is no clear definition or common understanding of key resource efficiency terminology and some countries' responses indicate that they have difficulty interpreting what 'resource efficiency' entails. Countries interpret resource efficiency quite broadly, and in fact only five countries define 'resources' in their strategies.

- The vast majority of countries surveyed do not have a dedicated resource efficiency strategy, but rather resource efficiency is addressed through other economy-wide policies, strategies or action plans. About six countries were found to be shifting from environmental policies to more integrated resource efficiency policies. Water and energy were the sectors most frequently covered in resource efficiency policies whereas, with the exception of transport, the service sectors did not appear to be a target for resource efficiency policies.

- The priority resources most commonly reported were energy carriers and waste, followed by minerals and raw materials (although it is not clear whether metals was included in this category and overall only 3 countries mentioned metals as a separate category) and water. When resources were grouped into broader categories, the top priorities were energy sources, biomass and raw materials.

- The strategic objectives set by countries are rather general and only 6 countries have strategic objectives that cover absolute qualities of resources used. Most countries reported having objectives related to SCP, with several countries reporting having objectives with regards to housing, mobility and food consumption, although most of these aimed to address consumption through technological advancements and not through managing demand. Only Sweden's objectives related to global environmental impacts of national consumption, whereas the Netherlands are addressing the environmental impacts embedded in international trade.

- Most countries do not have targets in place to address material efficiency and use of materials, although most have targets on waste, energy use and energy efficiency, air emissions such as greenhouse gas emissions and land use such as increasing the share of land used for organic farming (i.e. targets driven by EU requirements). There was inconsistency with regards to the level of detail and focus of indicators. The most commonly set indicators were in the areas of waste, energy and material use.

- EU countries see most value in sharing experience about economic and information-based instruments, with only a few countries mentioning research programmes or initiatives addressing household consumption.

- There was a great variety in the institutional set up for developing and implementing resource efficiency policies but, typically, four ministries are involved: environment, energy, economy and agriculture. This sometimes leads to overlapping competencies and unclear responsibilities.

- EU policy initiatives seem to be an important driver of resource efficiency policy development.

- Finally, countries were asked to identify their information needs and knowledge gaps, and this resulted in a list of over 50 issues. However, three emerged as the most important ones: 1. receiving information on how to best integrate resource efficiency into other policies; 2. sharing information and experience on good practice on issues such as on strategic objectives, targets and indicators; and 3. how to assess the effectiveness of various policy instruments.

Given the results from the survey, the EEA outlines the following considerations for future policies on resource efficiency:

- Resource efficiency policies can have synergies and trade-offs, therefore effort is necessary to ensure that resource efficiency policies are coherent with other key EU policies.

- One of the strong drivers for setting national resource efficiency policies were EU policy initiatives. This provides an opportunity for EU resource efficiency policies to give guidance and strategic direction. There is also scope for the EU to contribute to developing a common understanding of key concepts, sharing knowledge and experience, guiding work on the development of indicators and stimulating discussion on setting consumption targets.

- The survey demonstrated that there is no clear understanding and use of the terms and concepts related to resource efficiency. Therefore, it would be helpful to develop and communicate an understanding of the interlinkages, overlaps and synergies between the key concepts, while at the same time allowing individual nations to decide which policies and resources are most relevant in their national context.

- Resource efficiency policy should aim to target consumption as a priority, perhaps by using economic instruments to change consumption behaviour. Resource efficiency could also be strengthened with an increased focus on products, as this could also have a global knock-on effect for improving resource efficiency. The survey also highlighted the need to develop policies that take into account the global effects of a country's consumption. The EEA also highlights the importance of making a business case for resource efficiency.

- With regards to targets, the survey showed that common EU targets could be important in driving policy development at the national level.

- There is also the need to develop EU-wide integrated resource efficiency indicators. This would of course require cooperation between policy makers, statistical offices and research institutes.

- Finally, there is a need to strengthen the knowledge base for resource efficiency.

Practically all of the countries surveyed have developed, or are developing, strategies for resource efficiency, which often include waste management and recycling targets (particularly for WEEE and aggregates). Some countries also have in place, or are developing, legislation or plans specifically targeting the management of raw materials, including those metals that have been defined as critical. Table 13 lists these countries. Countries whose mineral strategies have been discussed earlier in the report (Finland, France, Germany and the Netherlands) are excluded from the table.

Country	Raw Materials Strategies/Plans/Legislations etc.
Austria	Austria has in place a Raw Materials Plan, developed as a survey of domestic raw material deposits and as a plan to preserve them for future generations. Due to concerns about possible real estate speculation the specifics of the plan are kept confidential. One of the Plan's strategic objectives is minimal use of primary minerals.
Belgium	The Flanders Region will be publishing a Sustainable Materials Management Strategy by mid 2012 whose main focus will be to achieve the maximisation of secondary raw material use in production processes, and the minimisation of impacts on the environment resulting from raw material mining and processing. Additionally, through its Environment and Energy Technology Innovation Platform the Flemish Government subsidises companies and research to develop sustainable products and processes, where the materials used must be maximally re-usable or fit into a closed cycle.
Bulgaria	The National Reform Programme 2010-2013 (under development) contains measures for the management of mineral resources.
Cyprus	Work is underway for setting targets for the minimisation of demand and increase in efficiency in the use of mineral resources.
Czech Republic	Raw Material Policy of the Czech Republic in the Field of Mineral Materials and their Resources (developed in 1999 and will be updated in 2011). The policy includes fuels, ores, industrial and building materials from both primary and secondary sources, but does not contain and has not led to a separate national resource efficiency strategy or a dedicated action plan for resource efficiency.

Denmark	The Danish Raw Materials Act has the purpose of making sure that supply and production of raw materials takes place in a natural and environmentally safe way.
Lithuania	The aim of the Lithuanian State Strategy of Use of Underground Resources (under preparation) is to ensure the rational use of mineral resources and contribute to the country's modern economic creation.
Poland	National Environment Policy for 2009-2012 and its outlook to 2016. Its main goals are to optimal supply of mineral resources to the public and businesses, and to protect resources from qualitative and quantitative deterioration. Specific actions until 2016 include: improving the regulatory framework for the protection of mineral resources and underground water reserves; limiting pressures on the environment from geological exploration and resource exploitation; eliminating illegal resource exploitation.
Romania	Romania has recently prepared a draft mining strategy (currently under approval) for the period 2010-2020 to supersede its Mining Industry Strategy 2004-2010. In Romania, mineral resources extraction activities are covered by Mining Law 85/2003. Priority actions include: efficient management and rational exploitation of useful mineral resources; providing investments in mining sector development; economic efficiency throughout the production chain; extraction in compliance with all the environmental protection principals. Mineral resource efficiency is targeted in the following lines of action: the capitalisation of mining products in a free market between internal and external suppliers; an integrated national system for monitoring the environmental impact caused by industrial mining activities as a tool of prevention, planning and emergency response; efficient management of natural resources to stabilise domestic prices.
Slovakia	Slovakia’s raw materials policy (2004) ensures effective exploration and use of minerals, meeting all criteria of sustainable development.

Slovenia	The National Mineral Resource Management Programme (2009) addresses efficient mineral resource management and covers the entire mining cycle from exploration, mine development and extraction to closure and remediation. There will also be a National Mining Strategy that will have an extensive focus on efficient mineral resource management. General aims and objectives: rational utilisation of natural (mineral) resources; management aimed at the provision of mineral resources and preservation of access to natural resources for future generations according to the principles of sustainable development; balanced provision of mineral resources from domestic sources; reduction of negative impacts on the environment and local communities; and, maximum knowledge and protection of the usability of mineral resources.
Spain	Law 22/1973 of Mines and its implementation. The Spanish Association on Standardisation (AENOR) has approved the Standard on Sustainable Mining Management Indicators, which aims at establishing social, environmental and economic indicators to assess sustainable mining management systems. This standard is to be applied to research, mining and mining waste. The requirements of the system are defined in the Standard on Sustainable Mining Management Systems. Both standards are voluntary.
Sweden	Sweden's Environmental Quality Objectives include the following: By 2015 at least 60% of phosphorus compounds present in wastewater will be recovered for use on productive land. At least half of this amount should be returned to arable land.

Table 13 Countries with raw materials strategies, plans of legislation (EEA, 2011)

5.2 Waste & Resources Action Programme (WRAP)

A 2009 WRAP report[12] identified 13 resource efficiency strategies that could contribute as much as 10% of the UK GHG emissions reduction target by 2020. This group of strategies includes both production and consumption strategies as follows:

- Production strategies: lean production, materials substitution, waste reduction, re-direction of landfill material, dematerialisation of the service sectors, strategies for sustainable building, and efficient use of existing infrastructure.
- Consumption strategies: lifetime optimisation, shift from goods to services, reducing food waste, dietary changes, restorative economy, and public sector procurement efficiency.

This 2010 report aims to quantify the effect of these 13 strategies on material use, water use and ecological footprint (WRAP, 2010). In assessing the effect on material use, the following materials were considered (split into two groups due to modelling restrictions):

1. Materials added directly to the model: iron ore and steel, wood and pulp products, plastics, and fertilisers (nitrogen, phosphates, potassium);
2. Soft-linked materials: aggregates, gypsum and plaster products, aluminium, copper, cobalt, lithium and rare earth elements.

Overall, resource efficiency strategies reduced water use by 5.8% relative to the reference scenario for 2020. Consumption strategies had a greater impact on reducing water use, and were responsible for over 90% of the reduction, whereas production strategies only accounted for about 10%. The most effective strategies were dietary change (5.1% reduction between 2010 and 2020) and reducing food waste (4.8% reduction) - both closely related to the agriculture sector which is responsible for the greatest water intensity - followed by lifetime optimisation.

Although the cumulative impact of all the strategies caused a decrease in the ecological footprint, the decreases were not enough to outweigh the underlying growth trend, resulting in an overall increase in impact. Again consumption strategies had the greatest impact on reducing the ecological footprint but production strategies were more significant than for water use, making up about 20% of the overall reduction. The most effective production strategy was lean production, whereas the most effective consumption strategies were lifetime optimisation, goods to services, reducing food waste and dietary changes.

The results for material use were split into two groups. For materials added directly to the model, the impact of each strategy varied according to the material assessed, although lean production was important for most indicators. For all of the materials (except

[12] WRAP (2009) Meeting the UK climate challenge: The contribution of resource efficiency.

fertilisers) the most effective consumption strategies were lifetime optimisation and goods to services. For fertilisers, dietary changes and reducing food waste were the most effective. With regards to soft-linked materials, the strategies had a minimal impact on the consumption of aggregates and gypsum and plaster. However, for other materials, cumulatively the strategies showed a 12% or greater reduction in use from the reference scenario to 2020, caused mainly by strategies that reduced consumption of electrical goods. For cobalt, copper and lithium the resource efficiency strategies caused such savings that the increased consumption to 2020 projected in the reference scenario was reversed. The consumption strategies that had the greatest impact are lifetime optimisation and goods to services whereas lean production seemed to be the most significant production strategy. When interpreting these results it should be borne in mind that the modelling did not take into account the impact of future technologies which will most likely increase the consumption of these materials.

Overall, the report draws the following conclusions:

- As expenditure on imports increases so does the associated environmental impact;
- Generally, strategies that in the 2009 WRAP report showed the greatest emissions reduction also had the greatest benefits for other indicators. Moreover, no conflicts between indicators were identified;
- Strategies that address consumption are at least as effective as production strategies; and
- Strategies that extend the life of goods or reduce the consumption of electronics and electrical goods have the greatest impact on material consumption.

Finally, as this was a first attempt at incorporating physical data into an input-output model the research faced challenges particularly regarding data availability. To address these for future work, the report makes a number of recommendations including improving the database on resource and product imports, improving data collection on water use across all sectors as well as encouraging other countries to do the same, investigating emerging technologies and their level of dependence on particular materials, and carrying out more specific modelling at the indicator or sub-sector level.

5.3 Aldersgate Group

The Aldersgate Group published a report which represents a first attempt to gather information on the protection of biodiversity and ecosystem services (BES), to enable companies to gain a better understanding of the issues in order to manage their reliance and impact on BES (Aldersgate Group, 2011). Using available literature and consultation with Aldersgate Group stakeholders, the report summarises five key points with regards to BES:

1. Economic success is dependent on a healthy environment and the sustainable use of resources

   In addition to a number of other negative impacts, such as air and water pollution and soil degradation, the loss of biodiversity also reduces the availability of the raw materials key to so many businesses. Therefore, there is a real business case for BES preservation. However, while carbon management has become a key issue for businesses and governments, BES still lags behind. This is because, unlike carbon, whose costs and benefits have been quantified, the business case for BES has not been defined as its measurement is not straight forward. Nonetheless, the issues of climate change and biodiversity conservation are very closely linked.

2. Prices and policy appraisal must include the value of BES

   Progress has been made in the valuation of BES, with one key publication being the UK National Ecosystem Assessment (2011), which estimates the annual value of various ecosystem services. However, it is noted that better valuation will have to become more mainstream and accounted for across the economic and trade ministries in addition to the environment department.

3. Using an economic model that is more efficient will reduce business costs and increase resilience

   Just like there is a limit to the amount of greenhouse gases that can be released into the atmosphere before irreversible climate change takes place, there are also limits that cannot be passed when it comes to BES. Businesses will need to rethink their economic models and make innovative investments to ensure more efficient resource use. This will need to take a holistic and integrated approach rather than one focussing on one resource at a time. Such action will not only lead to the protection of biodiversity but will also give businesses a competitive advantage by making them more resilient to global spikes in commodity prices.

4. Regulation will not only help protect the environment, but will also create new business opportunities and new markets

   For large scale change to occur, the Government must work together with business and the third sector to set a clear agenda for action and engage the consumer to bring about a change in behaviour. This will create business opportunities in the form of attracting new customers, penetrating new markets and ensuring the sustainability of the supply chain. Examples of business opportunities include eco-tourism and ecologically branded products. Certain tools are necessary to promote this change, including biodiversity performance standards and certification, assessment and reporting schemes, and voluntary schemes. Many of these are available or under development.

5. There are both costs and opportunities associated with BES, but businesses that take the lead and create a BES strategy are likely to lead the way

   The risks associated with BES include higher costs, reputational damage, new government regulation and loss of customers, whereas the opportunities include demand for new products, better access to capital and new revenue streams. As pressures on the natural environment increase, businesses that take the lead will have a competitive advantage. However, businesses require the necessary tools to be able to measure their material interactions with BES and suitable frameworks for reporting. While improvements in this respect have been made, the measurement of BES remains challenging and the Government must address these issues when it publishes its guidance on business environmental impact measurement and reporting in 2012.

The report then goes on to give seven case studies on companies that have taken measures to protect BES. Finally, it makes the following recommendations on the way forward:

- Natural capital must be included in national accounts and Government must clarify how this will be done. The Government must also ensure that there is proper scrutiny by an independent body.
- Alongside the fiscal budget, the Chancellor must also present a draft natural capital budget by the end of this Parliament.
- The Natural Environment White Paper set a zero net biodiversity loss target. For this to be met there must be cross-departmental responsibilities.
- Businesses should assess their dependence and impact on BES and develop measures to ensure that they use resources sustainably.
- Defra should work with businesses to develop a reporting framework and associated guidance for BES. It should also work with the Natural Capital Committee to ensure that the importance of BES to the economy is properly defined in the Natural Capital Budget and that the materials risks and opportunities to specific business sectors are highlighted.

5.4 Confederation of British Industries

A competitive, sustainable and low carbon economy can only be achieved through effective resource management. The Confederation of British Industries (CBI) published its 'Made to Last' report with the aim to facilitate the dialogue between government and industry in addressing this business issue by advocating the need to directly consider industry input and expertise in developing policy (CBI, 2011). According to CBI, there are three necessary steps for establishing the best policy landscape to support business efficiency:

Step 1: Recognise resource efficiency makes business and environmental sense and will be key to our future economy

In recent years resource supplies have been volatile, resulting in variable commodity prices. Material prices have increased and are likely to continue to do so as competition for them increases, in part due to growth in emerging markets. While energy has been a focus in recent years, other materials such as technology metals have also been affected. Therefore, resource efficiency not only makes environmental sense but also business sense as businesses can potentially reduce their costs and gain customers based on their environmental credentials. Businesses and policy makers alike can learn from existing good practice examples, some of which are showcased in the report in the form of case studies.

Step 2: Establish a shared set of indicators for resource efficiency before introducing targets

Before beginning to set targets for resource efficiency, businesses and government need to understand the current state of resource efficiency and where further improvements are needed – this requires the use of indicators. The CBI recommends that instead of using one general indicator as proposed by the EU Roadmap to a Resource Efficient Europe, it would make more sense to establish a series of indicators using a lifecycle approach across a range of resources. Secondly, the CBI recommends that an EU consultation takes place to bring together all stakeholder experience on existing indicator initiatives to better understand what has worked, what has not worked and what barriers need to be overcome. Lastly, in order to ensure that the indicators work the methodology has to be a global one, as supply chains are global. If the resulting EU methodology ends up being significantly different from what is currently used internationally it could cause fragmentation and confusion.

Step 3: Address policy and market risks to investment in resource-efficient products and services

To improve the overall investment environment and encourage businesses to invest in resource efficiency, the following must be addressed:

- Offer policy certainty, consistency and simplicity: a complex policy landscape acts as a deterrent for business investment. Therefore, before attempting to introduce new policies, it makes sense to focus on ensuring that policy instruments already working to promote resource efficiency are fully implemented. Ensuring that there is cross-governmental ownership of resource efficiency will also be key.

- Choose the right policy tools: it is important to review current resource efficiency regulation to ensure that it is still relevant and fit for purpose. However, while regulation is important, other tools such as voluntary action and market based instruments are also important.

- Adhere to the principle of 'think small first': policies should take SMEs' interests into account at the very early stages to avoid disproportionate burdens and unintended consequences. Furthermore, since medium enterprises are the ones that put greater emphasis on innovation in the UK, with innovation being key to resource efficiency, future resource efficiency policies must make sense for medium-sized enterprises.
- Work with industry to cultivate the right knowledge base: industry should be included in future government research proposals to ensure that the resulting evidence base is useful to it. Government delivery bodies must also remain relevant and take industry input into full consideration.
- Facilitate EU best practices in innovation and research sharing: this could be done through public procurement as well as through the development of joint technology initiatives in areas of resource efficiency.
- Equip our workforce with the right skills: as resource efficiency practices become more widespread, businesses will require skilled workforce. This can be obtained through industry input into the design of university and training courses.

References

Aldersgate Group (2011) Pricing the Priceless - The business case for action and biodiversity. Available here: http://www.aldersgategroup.org.uk/reports/

APS/MRS (2011) Energy Critical Elements: Securing Materials for Emerging Technologies. Available here: http://www.aps.org/policy/reports/popa-reports/upload/elementsreport.pdf

Angerer G., Erdmann L., Handke V., Lullmann A., Marscheider-Weidemann F., Mawede M., Scharp M. (2009) Raw materials for emerging technologies. The influence of sector-specific feedstock demand on future raw materials consumption in material-intensive emerging technologies. Available here: http://publica.fraunhofer.de/eprints/urn:nbn:de:0011-n-1115143.pdf

Bleher D., Buchert M., Schüller D. (2009) Critical Metals for Future Sustainable Technologies and their Recycling Potential. Available here: http://www.resourcefever.org/detail/items/critical-metals-for-sustainable-technologies-and-their-recycling.html

BGS (2011) Risk List 2011. Available here: http://www.bgs.ac.uk/mineralsuk/statistics/riskList.html

CBI (2011) Made to last – creating a resource efficient economy. Available here: http://www.cbi.org.uk/media/1218447/cbi_-_made_to_last_-_creating_a_resource_efficient_economy.pdf

COM (2008) 699 ‘The raw materials initiative - meeting our critical needs for growth and jobs in Europe’

COM (2011) 25 ‘Tackling the challenges in commodity markets and on raw materials’

Defra (2010) Review of the Future Resource Risks Faced by UK Businesses and an Assessment of Future Viability (SCP0905/EV0458). Available here: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17161&FromSearch=Y&Publisher=1&SearchText=EV0458&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Dobbs R., Oppenheim J., Thompson F., Brinkman M., Zornes M. (2011) Resource Revolution: Meeting the world’s energy, materials, food, and water needs. Available here: http://www.mckinsey.com/Features/Resource_revolution

Dozolme P. (n.d.) Securing Metals Sourcing: The Emergence of a New French Policy? About.com. Mining. Available here:

http://mining.about.com/od/UnderseaExploration/a/Securing-Metals-Sourcing-The-Emergence-Of-A-New-French-Policy.htm

Dutch Ministry of Foreign Affairs (n.d.) Dutch Government Policy Document on Raw Materials. Available here: http://www.minbuza.nl/en/key-topics/development-cooperation/dutch-development-policy/millennium-development-goals-mdgs/dutch-aim-for-mdg-7/dutch-government-policy-document-on-raw-materials.html

EEA (2011) Resource efficiency in Europe – Policies and approaches in 31 EEA member and cooperating countries. Available here: http://www.eea.europa.eu/themes/economy/resource-efficiency/resource-efficiency

Environmental Protection Administration (2010) Zero waste and resource recycling promotion. Retrieved January 20, 2012 from http://www.epa.gov.tw/en/epashow.aspx?list=112&path=12305&guid=54ed0a74-3dc5-42c5-9250-0fbf51f92dc3&lang=en-us

ETC/SCP (2011) Green economy and recycling in Europe. Available here: http://scp.eionet.europa.eu/publications/2011_wp5

European Commission (2010) Critical Raw Materials for the EU, Report of the Ad-hoc Working Group on defining critical raw materials. Available from http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf

Federal Ministry of Economics and Technology (2010) The German Government's Raw Material Strategy - Safeguarding a sustainable supply of non-energy resources for Germany. Available here: http://www.bmwi.de/English/Redaktion/Pdf/raw-materials-strategy,property=pdf,bereich=bmwi,sprache=en,rwb=true.pdf

Financial Times Deutschland (2011) Berlin Intends to Subsidise Search for Raw Materials. *Financial Times Deutschland*, 18 November 2011. Translation provided by Kenan Poleo (FCO Germany) (pers. comm.).

Hislop H., Hill J. (2011) Reinventing the Wheel: a Circular Economy for Resource Security. Available here: http://www.green-alliance.org.uk/grea_p.aspx?id=6044

House of Commons [Science and Technology Committee] (2011) Strategically important metals – Fifth report of session 2010-2012. Available here: http://www.parliament.uk/business/committees/committees-a-z/commons-select/science-and-technology-committee/news/110517-sims-report-published/

IOM3 (2011) Energy Materials Group Conference Proceedings of February 28, 2011: Sustainable Materials for Emerging Energy Technologies. Available here: http://www.iom3.org/conference-proceeding/sustainable-materials-emerging-energy-technologies?c=621

KfW (2011) Press Release of 10 November 2011 - KfW Study: Lack of raw materials endangers future viability of German economy. Available here: http://www.kfw.de/kfw/en/KfW_Group/Press/Latest_News/PressArchiv/2011/20111110_54444.jsp

Kosich D. (2011) Proposed German industrial alliance aims to secure critical metals supply. *Mineweb,* 22 November 2011. Available here: http://www.mineweb.com/mineweb/view/mineweb/en/page72068?oid=140136&sn=Detail&pid=92730

METI (2008) Press Release of 28 March 2008 - Guidelines for Securing Natural Resources. Available here: http://www.meti.go.jp/english/press/data/nBackIssue20080328_05.html

METI (2009) Press Release of 28 July 2009 - Announcement of "Strategy for Ensuring Stable Supplies of Rare Metals". Available here: http://www.meti.go.jp/english/press/data/20090728_01.html

MIT (2010) Strategies and perspectives for securing Rare Metals in Korea - a talk by Dr Jung-Chan Bae of the Korea Institute of Industrial Technology. From: MIT Energy Initiative Workshop Report, Critical elements for new energy technologies. Available here: http://web.mit.edu/miteicomm/web/reports/critical_elements/CritElem_Report_Final.pdf

Morley N., Etherly D. (2008) Material Security, Ensuring Resource Availability for the UK Economy. Available here: http://www.oakdenehollins.co.uk/pdf/material_security.pdf

Moss R.L., Tzimas E., Kara H., Willis P., Kooroshy J. (2011) Critical Metals in Strategic Energy Technologies - Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies. Available here: http://setis.ec.europa.eu/newsroom-items-folder/announcement-new-report-on-critical-metals-in-strategic-energy-technologies

Nurmi P.A., Lahtinen R., Vuori S. (2010) Finland's Mineral Strategy. Available here: http://www.mineraalistrategia.fi/etusivu/fi_FI/etusivu/_files/84608401427464240/default/FinlandsMineralsStrategy.pdf

Oakdene Hollins (2011) Study into the feasibility of protecting and removing critical raw materials through infrastructure development in the south east of England. Available here: http://www.environment-agency.gov.uk/static/documents/Business/EPOW-recovering-critical-raw-materials-T5v2.pdf

Oakdene Hollins (2010) Lanthanide Resources and Alternatives. Available here: http://www.oakdenehollins.co.uk/metals-mining.php

OECD (2009) ENV/EPOC/WGWPR(2009)8/FINAL A sustainable materials management case study – Critical metals and mobile devices. Available here:

http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WGWPR(2009)8/FINAL&docLanguage=En

PBL (2011) Scarcity in a sea of plenty? Global resource scarcities and policies in the European Union and the Netherlands. Available here: http://www.pbl.nl/en/publications/2011/Scarcity-in-a-Sea-of-Plenty-Global-Resource-Scarcities-and-Policies-in-the-European-Union-and-the-Netherlands

PwC (2011) Minerals and metals scarcity in manufacturing: the ticking timebomb. Available here: http://press.pwc.com/GLOBAL/minerals-and-metals-scarcity-in-manufacturing-a-ticking-timebomb/s/63f25ead-0d77-428b-84b5-e7ab27ac9851

Resnick Institute (2011) California Institute of Technology. Critical Materials for Sustainable Energy Applications. Available here: http://resnick.caltech.edu/learn/docs/ri_criticalmaterials_report.pdf

Silk Road Intelligencer (2011) Kazakhstan, France talk rare earths and energy during Nazarbayev’s visit to Paris. *Silk Road Intelligencer*, 21 September 2011. Available here: http://silkroadintelligencer.com/2011/09/21/kazakhstan-france-talk-rare-earths-and-energy-during-nazarbayevs-visit-to-paris/

SIN and Technology Strategy Board (2011) Resources that Don't Cost the Earth – Encouraging European Solutions and Collaboration Workshop, British Embassy Berlin, 1-2 December 2011. Presentations available here (registration required): https://connect.innovateuk.org/web/material-security/news;jsessionid=BDB7DE0C308AE05A8F0399E1C6B17EBB.MekushUdbew4?p_p_id=62_INSTANCE_33Xj&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_count=1&ns_62_INSTANCE_33Xj_struts_action=%2Fjournal_articles%2Fview&ns_62_INSTANCE_33Xj_groupId=3491455&ns_62_INSTANCE_33Xj_articleId=6219962&ns_62_INSTANCE_33Xj_version=1.2

Statistics Netherlands (2010) Critical materials in the Dutch economy – Preliminary results. Available here: http://www.cbs.nl/NR/rdonlyres/37ADC207-2FD4-4D34-B5DE-02A3ADBDF3B4/0/criticalmaterialsinthedutcheconomy.pdf

Stratman K. (2011) Together in Search of Raw Materials. *Handelsblatt*, 17 November 2011. Translation provided by Kenan Poleo (FCO Germany) (pers. comm.).

U.S. DOE (2010) Critical Materials Strategy. Available here: http://energy.gov/downloads/us-department-energy-critical-materials-strategy-0

U.S. DOE (2011) Critical Materials Strategy. Available here: http://energy.gov/articles/department-energy-releases-its-2011-critical-materials-strategy

UNEP (2010) Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials, A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management. Hertwich, E., van der Voet, E., Suh, S., Tukker, A, Huijbregts M., Kazmierczyk, P., Lenzen, M., McNeely, J., Moriguchi, Y.

UNEP (2011a) Assessing Mineral Resources in Society: Metal Stocks and Recycling Rates, Summary booklet based on the two reports of the Global Metal Flows Group 'Metal Stocks in Society: Scientific Synthesis' and 'Recycling Rates of Metals: A Status Report'. T.E. Graedel, M. Buchert, B.K. Reck, G. Sonnemann.

UNEP (2011b) Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A.

Waste Management World (2011) Rare Earths to be recycled from magnets in France. *Waste Management World*, 6 October 2011. Available here: http://www.waste-management-world.com/index/display/article-display.articles.waste-management-world.recycling.2011.10b.Rare_Earths_to_be_Recycled_from_Magnets_in_France.QP129867.dcmp=rss.page=1.html

WEF (2012) Global Risks Report 2012. Available here: http://www.weforum.org/issues/global-risks

WEF RRN (2011) The political and economic implications of resource scarcity. Available here: http://www.weforum.org/content/pages/political-and-economic-implications-resource-scarcity

WRAP (2010) Securing the future – The role of resource efficiency. Available here: http://www.wrap.org.uk/downloads/FULL_REPORT_v2.a8ca15a2.10014.pdf