Resources that Don't Cost the Earth

Encouraging European collaboration and solutions

Workshop report and case studies

RSC | Advancing the Chemical Sciences

British Embassy
Berlin

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About this publication

The *Resources that Don't Cost the Earth* workshop was held at the British Embassy in Berlin, 1-2 December 2011. It was organised in partnership with the UK Science & Innovation Network and the Materials Security Special Interest Group. It brought together around one hundred leading academics, industrialists and policymakers from across Europe to discuss issues related to the supply of certain rare or critical elements, and to identify sustainable ways to address the security of supplies of materials.

This report is a summary, for participants, of the key issues discussed at the workshop. It also contains case studies that illustrate innovative and sustainable solutions to resource scarcity. The report is also likely to be of relevance more widely to people with interests in resource efficiency, materials security and sustainability.

http://rsc.li/resource-efficiency

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The UK Science & Innovation Network (SIN) consists of around 90 staff based in 40 British Embassies, High Commissions and Consulates, across 25 countries around the world. The network is jointly funded by the Foreign & Commonwealth Office (FCO) and the Department for Business, Innovation and Skills (BIS). SIN officers engage with the local science and innovation community in support of UK policy overseas. In line with FCO and BIS priorities, the objectives of SIN are to:

- influence science and innovation policies of governments, businesses and academia to benefit the UK;
- inform UK policy development through identifying good practice internationally;
- facilitate international science collaboration of best with best to benefit the UK; and
- facilitate international innovation collaboration to augment UK capabilities.

The SIN works closely with a wide range of partners from government, business and academia. It aims to complement the work of other key partners such as UK Trade & Investment (UKTI), The British Council, Research Councils UK (RCUK) and the Department for International Development (DFID).

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www.bis.gov.uk/sin

About the Materials Security Special Interest Group

A special interest group of the Chemistry Innovation, Environmental Sustainability and Materials Knowledge Transfer Networks.

https://connect.innovateuk.org/web/material-security

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Executive summary

One of the greatest challenges facing global society is satisfying the demand for goods and services while minimising the environmental and financial impact of providing these resources. This is set against a backdrop of rapidly growing populations and economies.

There are many factors that influence the supply of, and the demand for resources and the many ways in which resources can be used more efficiently. There is tremendous scope for change in the design and manufacture of goods, as well as the consumption, use and disposal of products. Strategies such as recycling, design for disassembly, remanufacturing and new business models which combine or substitute processes all have the potential to contribute to a shift in the quantity and types of materials used as well as keeping key elements in the supply chain for longer.

A shift to more resource-efficient supply chains will require substantial support from governments internationally in the form of information and guidelines, regulations and incentives for the various players in each supply chain. There is also scope for technological advances and for the development of alternative processes and materials to make significant contributions.

Introduction

There is a growing awareness that raw material and feedstock resources for both established and emerging industries are becoming increasingly scarce. Germany, the UK and other European countries are almost exclusively dependent on the import of strategically important metals and rare earth elements for their technology sectors. As global demand for strategic elements increases, European countries become more vulnerable to shortfalls in supply.

In 2009 the Royal Society of Chemistry (RSC) consulted with its members to identify ways in which the chemical sciences will contribute to addressing the major challenges associated with sustaining our growing global population and increasing standards of living. Two of the key challenges identified by the chemical sciences community were the conservation of scarce natural resources and sustainable product design.

In June 2010 the European Commission published a report on critical raw materials and has published a list of 14 economically important raw materials which are subject to a higher risk of supply interruption.[1] This includes resources that are used in manufacturing in diverse sectors such as automotive and aircraft components, cemented carbide tools, construction and steel, electrical and electronic equipment.[2]

In 2010 the UK House of Commons Science and Technology Select Committee carried out an inquiry on strategically important metals[3] and the German Government published its Raw Materials Strategy.[4]

In response to these issues, the RSC hosted a workshop in London, *Materials that Don't Cost the Earth*[5] examining the complex challenges and opportunities faced by the energy and consumer product sectors that rely on scarce natural resources to manufacture their products. This was followed by *Resources that Don't Cost the Earth*, held in partnership with and hosted by the UK Science Innovation Network at the British Embassy in Berlin in December 2011.

Resources that Don't Cost the Earth brought together leading academics, industrialists, government agencies and policymakers from across Europe to identify challenges and solutions related to resource efficiency as well as opportunities for collaboration. Keynote lectures provided an overview of current knowledge about resources and reserves, the drivers of resource demand and the geopolitical and economic developments that can lead to fluctuations in the supply of scarce resources. The programme for the workshop is given in Appendix B.

This report summarises the discussions at the workshop. Part 1 presents the key issues and ideas for solutions which relate to specific sections in the supply chain, while Part 2 focuses on the overarching issues relevant to the supply chain.

A highlight of the report is the case studies, given in Appendix C. These have been provided by workshop participants and give detailed concrete examples of current approaches to tackling the challenges of resource efficiency including: ideas from academia about new materials (graphene); emerging technologies (thin-film photovoltaics) and extraction of phosphorus from waste water; novel approaches to recycling and to waste management in different industrial sectors; initiatives by government agencies to support businesses, including SMEs; and, analyses and initiatives to raise awareness and understanding of the origins and impact of materials scarcity.

1 Opportunities along the supply chain

This section considers issues related to resource efficiency in different parts of the supply chain. Participants discussed approaches to resource efficiency at the sourcing, manufacturing, waste management, product design and end-of-product life stages. They also identified the potentially important role of consumers.

1.1 Access to rare resources

Metals and minerals are essential to economic development. The demand for these resources is rising, in developed countries as well as in developing countries, so mining will remain a part of sourcing strategies. This is a major concern because the current economically viable ore deposits are not predicted to meet the anticipated increase in demand. Also, some mineral reserves are located in protected conservation habitats and are therefore unavailable for mining (see case study 12).

Routes to enabling the extraction of resources and to increase access to resources are:

1.1.1 **Exploration of new deposits:** Strategies such as recycling and materials substitution cannot currently safeguard the supply of rare earth elements and strategic metals. Consequently, the need for virgin material remains and exploration of new terrains is essential. This can be facilitated by advances in the technological frontier (eg deep drilling).

1.1.2 **Re-evaluation of existing deposits:** Due to changing economic or geopolitical factors, sources that were once considered economically unviable or inaccessible may have the potential to become workable deposits.

1.1.3 **Replenishing live reserves:** Recycling and reclaiming minerals and metals reduces the waste going to landfill. It is also a way of keeping the materials in the supply chain and so reducing the need for virgin material. The idea of 'secondary resource mining' is discussed in section 1.3.

1.1.4 **Overcoming environmental constraints on exploration and mining:** The development of non-invasive mining techniques may enable extraction of resources in areas protected for environmental reasons.

1.1.5 **Partnership and collaboration to secure resources:** Collaborations and partnerships that facilitate the sharing of key technologies and materials are likely to be essential. These could include the following.

- National raw materials strategies involving co-operation between business and government to support access to key resources along the whole supply chain (from exploration to recycling).
- International agreements such as the raw materials partnership agreement between Germany and Mongolia (2011) where Germany supports sustainable economic development in Mongolia and secures access to critical raw materials.[6]
- Industry-driven sourcing agreements and alliances, for example between mining and manufacturing sectors.

1.1.6 **Aid arrangements:** Fair-trade and/or bilateral agreements are a means of ensuring that materials are ethically and sustainably sourced. The sharing of profit, to include the early stages in the supply chain, is also likely to reduce conflict over resources.

1.2 Substitution of materials, processes and business models

Substitution of materials is one strategy that could tackle limitations on supplies of critical resources. The following issues relate to the concept of substitution.

1.2.1 **Materials substitution from a business perspective:** There is a need to better understand the practicality of substitution in real business contexts, including a review of how materials substitution can help or hinder business.

1.2.2 **Situations where materials substitution is initially ineffective:** Substituting one material for another can create new kinds of resource constraints, for example because the alternative material is itself scarce or the substitution involves alternative processes which use more energy. This can be overcome, for example, by finding new ways to produce the alternative material. See case study 1 (Appendix C).

1.2.3 **Situations where materials substitution is impossible:** Some materials cannot easily be substituted as is the case, for example, for phosphorus, a key element in fertilisers. Here an alternative strategy is to reduce the demand for phosphorus by maximising the efficiency with which the nutrient is delivered to crops. Another approach is to reclaim the element. See case study 2.

1.2.4 **Substitution of processes:** The concept of substitution can be extended to substitution of one process for a more resource efficient alternative in a given business model. One example, from the National Industrial Symbiosis Programme (UK), is a collaboration between PSA Peugeot Citroën and Biffa to handle packaging waste.[7]

1.3 Cost efficient and innovative recycling

The increasing threat of disruption to materials supply leads to a re-assessment of waste as a secondary resource. For example, there is more gold in one tonne of computer scrap (although this is not currently easily extracted) than is present in 17 tonnes of virgin ore.

Future recycling strategies could include the following.

1.3.1 **Improving the quality of recycled materials:** Some materials do not suffer any degradation in quality during recycling and therefore are costed at the same price as the virgin material. In cases where a material degrades during recycling, additional processing is required before reintroducing the material to the supply chain. Technological advances are therefore needed to ensure that the cost of the recycled material at the grade required by industry is competitive with that derived from the virgin material. See case study 3.

1.3.2 **Creating new business opportunities:** In addition to high-throughput recycling of glass and steel there are emerging business opportunities associated with recycling products of new technologies. Countries that lead the development and implementation of recycling systems associated with new technologies will have a competitive advantage in terms of both export markets and domestic resource efficiency.

1.3.3 **Recycling as adding value to business:** Current business-to-business recycling in the chemicals industry – such as the recycling of precious metals used in catalysis – illustrates the value added by the smart recycling and handling of waste. See case study 4.

1.3.4 **Creating legislative support and setting standards:** Approaches include: adopting waste directives, for example by certifying plants and making flows of strategic resources transparent; introducing incentives to improve recycling rates; linking national and EU initiatives; and preventing illegal waste exports.

1.4 Supporting resource efficiency in manufacturing

A move to the efficient use of resources in a given manufacturing process should be seen as a business opportunity rather than an additional cost. The German and UK governments and their agencies already recognise this, and support businesses in reaping the benefit of associated cost savings. The following challenges have been identified.

1.4.1 **Guides and examples for business:** Guides and examples provide a useful way of illustrating economic opportunities associated with, and practical strategies for, introducing resource efficiency in manufacturing. An example is the resource efficiency strategy developed by the Association of German Engineers Resource Efficiency Centre (VDI-ZRE), set up at the recommendation of Germany's Federal Environment Agency (UBA). See case study 5.

1.4.2 **Identification of business opportunities:** New technologies that enable increased resource efficiency in manufacturing can present considerable opportunities. Consequently, a clear understanding of emerging technologies and technological gaps will place countries and sectors in a position to become market leaders. See case study 5.

1.4.3 **Support for SMEs:** Collaborations between SMEs and between SMEs and larger companies can enable SMEs to develop and adopt innovative elements of manufacturing processes by giving them access to more facilities and expertise.

1.4.4 **Reducing waste:** One way in which resources can be used more efficiently is by reducing waste produced during manufacturing. An example of how this can be achieved is *near net shape manufacturing technology* – meaning that components are manufactured to resemble the finished products – which reduces both initial material demand and the quantity of waste generated. See case study 6.

1.5 Remanufacturing and reuse

The remanufacturing and reuse of products provide other avenues to increasing the lifetime of key materials within the supply chain. The British Standards Institute has adopted Winifred Ijomah's definition of remanufacturing: 'Remanufacturing is a process of returning a used product to at least OEM [Original Equipment Manufacturer] original performance specification from the customer's perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent'.[8]

In the UK, remanufacturing and reuse is a £5 billion industry with some 50,000 employees. Reuse within businesses has clear financial benefits. Remanufacturing components can help businesses to maximise their margins by keeping components in the product cycle for longer. The consumer market for reuse and for remanufactured products depends on consumer behaviour and attitudes. Challenges and solutions related to remanufacturing and reuse include the following.

1.5.1 **Need for new business models:** Reused and remanufactured goods need to compete in the same market as new products, sometimes produced by the same company. New business models and strategies may therefore be required to make remanufacturing and reuse profitable, especially in volume-driven sectors where the manufacture of new products may be less costly. One strategy is to identify different markets for new and remanufactured products.

1.5.2 **Quality assurance:** Remanufactured and reused goods must undergo strict quality assurance and performance testing to ensure that there is no difference between new and remanufactured products. See case study 7.

1.5.3 **Consumer acceptance:** Remanufactured goods or components (such as remanufactured starter motors in new cars) may be perceived by consumers to be inferior. One way to address this perception is to have clear warranties covering the quality and servicing of the remanufactured product at the same level as its new equivalent.

1.6 Sustainable product design

There is an increasing realisation that product design is also critical to sustainability and resource security: product design has an impact on resource efficiency during manufacture and on reclaiming resources at the end of product life. The following are some of the routes to help maximise the potential role of product design in resource efficiency.

1.6.1 **Raising awareness of the role of design:** It is important to create opportunities for product designers to understand their role in resource efficiency. This includes provision of information and training about the key resources in materials and components; the impact of product lifetimes on supply chains; and the role of product design in enabling product disassembly and therefore recycling, remanufacture and reuse.

1.6.2 **Influencing consumer behaviour:** Product designers can play a role in influencing consumers to choose products which are made using more sustainable materials and processes by making them more appealing.

1.6.3 **Regulation to promote sustainable design:** There is an opportunity for governments and industry to review the roles of regulation related to manufacturing and design, at both national and EU level. It is important to understand how regulation can either inhibit or promote sustainable product design.

1.6.4 **Collaboration between product designers, engineers and scientists:** It is important that the expertise of product designers, engineers and scientists is pooled in order to integrate resource efficiency considerations at the product design stage.

1.7 The role of consumers

Consumers of manufactured goods are key stakeholders in issues related to resource efficiency. There are various ways in which consumers should be made more aware of the issues so that they can then contribute to initiatives to increase resource efficiency.

1.7.1 **Raising consumer awareness:** There is a need to increase awareness of resource efficiency issues as this will enable consumers to make informed choices about purchasing and using products. See case study 8. Clear information is needed concerning:

- the kinds of materials used in consumer goods as well as their origins;
- the implications of simply sending consumer products to landfill rather than recycling them or using them for longer – for example 90 million mobile phones corresponds to about £150 million of precious metal;[9]
- the implications of hibernating stock, for example keeping old mobile phones in a drawer or loft;
- the concept that remanufactured and recycled products are of the same quality as new products and provide a way of keeping materials within a supply chain for longer; and
- how to maximise the environmental or economic benefits of products that have the potential to increase resource efficiency. For example, avoiding trends such as consumers leaving lights switched on more because of the availability of energy-saving light bulbs.

1.7.2 **Providing incentives for recycling and resource efficiency:** One way to encourage recycling and resource efficiency more broadly is by providing incentives for consumers to recycle or to send products back to suppliers at the end of life.

1.7.3 **Regulations and warranties:** Regulations and warranties are an important way to protect consumers and to give them confidence in new products or systems which are based on recycled materials.

1.7.4 **Consumers as advocates for resource efficiency:** If consumers have sufficient information and act upon this they will create a demand for products and systems that contribute to resource efficiency. This kind of market influence will ultimately stimulate change in other areas of the supply chain. Consumers also have a role in lobbying on issues such as regulation to verify recycling standards, fair trade and the origin of materials.

2 Cross-cutting themes

It is clear that there are opportunities to optimise the efficient use of resources at every stage in the supply chain – from extraction and refining, to product manufacture and use, to the end of a product's life.

Some overarching themes also emerged at the workshop, like the importance of knowledge and skills. Examples of diverse activities requiring specialised knowledge and skills are: mining; estimating current and future reserves and resources; processing recycled materials to the grade required in an industrial process; and product design. Maintaining skill levels and embedding ideas related to sustainability is an important mission for education systems at all stages. Other cross-cutting themes were: information and data; business models and systems; and standards and regulations.

2.1 Information and data

Most supply chains are complex global systems involving many stakeholders and stages. Consequently it is important to establish a common understanding and assessment of the status of challenges and solutions related to resource efficiency. There is a need for reliable, consistent data on key materials. Given the global nature of many supply chains, this will often need to be collated at an international level. Such tools will help businesses and governments to assess the potential risks associated with disruption to material supplies. The following are examples of areas where participants suggested there is an opportunity to create or improve information resources.

2.1.1 **Standardisation of terminology:** There are currently many words and terms in use to describe aspects of resource efficiency. Examples include words like 'resource', 'reserves', 'materials' and 'sustainable', and compounds such as 'resource base', 'unidentified resources', 'critical materials, 'scarce metals', 'strategic metals'. The term 'resource efficiency' itself can be used to describe a range of issues and solutions. For example, it sometimes includes energy and sometimes focuses only on materials. The variation of terminology reflects the complexity of the issues and systems under discussion, but it would be useful, where possible, to establish some clearly defined terminology to aid communication across sectors, stakeholders and countries.

2.1.2 **Reliable estimates of international resources, reserves and stock:** There is a need for more reliable estimates and predictions of reserves and the resource base.

2.1.3 **Forecasting and modelling:** Forecasts of factors relating to the supply and cost of materials can be important tools for governments and for industry in planning and in safeguarding against fluctuations of supply and cost. There is a need for both short- and longer-term forecasting to make such planning possible. In addition to requiring accurate and comprehensive input data, the reliability of forecasting will depend on the models used. This is a challenge because of the complex set of internal and external factors which influence the supply chain and the status of particular materials. Models need to include diverse factors and scenarios such as:

- predictions about population growth and its effects on demand;
- possible changes in legislation and incentives;
- evolution in geopolitical circumstances;
- new technologies and processes;
- movement of resources especially in finished products;
- discovery of new mineral reserves or extraction techniques; and
- models for deposit formation.

2.1.4 **Resource criticality relevant for industry:** Expert analysis of critical metals is crucial. An example is a list prepared for the European Commission of 14 economically important raw materials which are subject to a high risk of supply interruption.[10] It is important to understand that the criticality of a given raw material will vary across industrial sectors and individual countries, meaning that deeper analysis may be required to assess criticality in different contexts. This may be complicated as a consequence of the confidential and strategic nature of certain information in both business and government (see case study 11).

2.2 Business models and systems

Changes to aspects of how businesses plan and operate across the supply chain from extraction to end-of-life product management are important to ensure efficient use of resources. Part 1 discusses ideas and solutions relevant to different business sectors that are part of a given supply chain. Below are some of the overarching themes for business which may require legislative, regulatory, societal or financial support.

2.2.1 **Resource management perspective:** Across the supply chain, it is important to move from a 'waste management' to a 'resource management' perspective within and between businesses.

2.2.2 **New business models:** There needs to be a shift from volume-based models dependent on large quantities of virgin material to business models that consider resource efficiency across supply chains.

2.2.3 **Industrial symbiosis:** Waste generated in one value chain can be introduced as a valuable resource for another, perhaps in a different industrial sector. Modest public-sector support can successfully facilitate this stakeholder collaboration, creating value and leading to investment, growth and jobs. See for example the National Industrial Symbiosis Programme (NISP) in the UK given in case study 9.

2.2.4 **Resource efficiency performance indicators:** Inclusion of resource efficiency related performance indicators in addition to standard financial performance indicators could provide an incentive for businesses to adopt new resource efficient practices and provide investors with additional options.

2.3 Standards and Regulations

Widespread introduction of resource efficient practices across supply chains at national and European level will require new standards and regulations. For example, acceptance of remanufactured and recycled products and alternative materials requires standard wording, regulations and design in order to provide clarity for both manufacturers and consumers. Progress can be made in the following key areas.

2.3.1 **Regulations to support resource efficiency:** Regulations are one way of supporting and providing oversight of sustainability management across the supply chain, from ensuring that extraction methods are both safe and environmentally robust, to protecting against the illegal export of waste (see case study 10). According to the European Network for the Implementation and Enforcement of Environmental Law (IMPEL) there are irregularities with over 50% of waste being exported.[11]

2.3.2 **Ethically and sustainably sourced minerals and strategic metals:** There is a need for policy measures, such as the G8 initiative during the German Presidency in 2007, to develop and implement mechanisms to certify that sources of virgin and other materials are ethically and sustainably sourced.

2.3.3 **Tracing elements across manufacturing steps:** It is sometimes the case that many stages are involved in the production of materials, components and final products. This means that companies at the end of the manufacturing chain may not be aware of the elements in their raw materials and components or of their environmental impact up-stream. This knowledge is essential and can be important for product design.

2.3.4 **Clear warranty standards and oversight:** There is a need to develop and implement robust warranty standards for reused and remanufactured goods which apply internationally. This will be important in addressing consumer perceptions, discussed in section 1.7 above.

Conclusion

There are many changes that can be pursued in different parts of any supply chain with the overall goals of minimising the quantities of key elements used and keeping those elements in the supply chain for longer. This begins with more efficient or less invasive approaches to extracting key elements, and ends with consumer understanding and new approaches at end-of product life including recycling, reclaiming and reuse. In between there are many opportunities to embed resource efficiency considerations into design and manufacturing, for example by reducing waste, investigating alternative processes and materials, remanufacturing and designing products for easy disassembly.

These kinds of changes, required of stakeholders across the supply chain, will need considerable effort and external support. This includes putting in place strong regulatory frameworks and useful guidelines and incentives for businesses, as well as providing information tailored to the needs of different stakeholders. Underpinning progress will be academic and industrial research leading to the development of new or alternative technologies, processes and materials.

It is clear that there is both a need and an opportunity for those involved with each supply chain to contribute to optimising the efficiency with which resources are used. Many of the solutions presented in this report require several stakeholders to act in concert and it is unlikely that major improvements will happen if they act alone.

In summary, there are many challenges associated with resource efficiency which need to be tackled on many different fronts. Some of these challenges are similar to those which have been faced before, so we will benefit from understanding history.[12] Participants in the workshop provided excellent examples of both good practice and new approaches to tackling problems which will form a very sound basis for future initiatives.

Appendix A: Acknowledgements

This summary report was prepared by:
Charlotte Beard and **Deirdre Black**, Royal Society of Chemistry (RSC).
Ursula Roos, UK Science and Innovation Network, Germany (SIN).

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Dr Mike Pitts, UK Chemistry Innovation Knowledge Transfer Network
Dr David Gardner, UK Environment and Sustainability Knowledge Transfer Network
Kenan Poleo, UK Science and Innovation Network, Germany

For comments or queries please contact **sciencepolicy@rsc.org**.

Appendix B: Workshop programme

12:30 Registration and lunch

13.30 Simon McDonald, British Ambassador
Welcome

13:35 Mike Pitts/David Gardner, Chemistry Innovation and Environmental Sustainability KTNs
Introduction: workshop objectives

Overview keynotes

Introduction and chair: Philip Strothmann, Secretariat of the International Resource Panel, UNEP

13:45 Volker Steinbach, Federal Institute for Geosciences and Natural Resources
The Role of the German Mineral Resources Agency

14:05 Gus Gunn, Science for Minerals & Waste, British Geological Survey
Critical Metals for European Industry – A Geological Perspective

14:25 Andy Clifton, Aerospace, Defence, Security & Space Trade Association –
Design for Environment Working Group
Assessment of Material Supply Risks – An Industry Perspective

14:45 Discussion

15.10 Networking break

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

Introduction and chair: Nick Morley, Oakdene Hollins

15:25 Carsten Rolle, Confederation of German Industry (BDI)
German Industry's Approach to Resource Partnerships

15:45 Steve Howdle, Professor of Chemistry, University of Nottingham
Keeping Society Supplied with 'Stuff' – The Need for Sustainable Chemical Processing

16:05 Michel Rademaker, Deputy Director, The Hague Centre for Strategic Studies
Geopolitics, Resource Nationalism and Forming Resource Partnerships

16:25 Discussion

16:50 Networking break

Part II Resource efficiency and sustainable alternatives (substitutes)

Introduction and chair: David Peck, University of Delft

17:05 Karl Coleman, Durham Graphene Science
Graphene Applications

17:25 Werner Maass, Deputy Director, VDI Centre for Resource Efficiency (ZRE)
The Challenge of Resource Efficiency: Best Practice and Solutions for SMEs

17:45 Francesco Masi Catalyst R&D Manager, Polimeri Europa
The Substitution of Rare Earths in the Polymerisation Process

18:05 Rachel Lombardi, International Synergies Limited
Cross-Industry Resource Efficiency and Sustainability Through Industrial Symbiosis

18:20 Discussion

Part III Cost efficient and innovative recycling

Introduction and chair: Ulrich Teipel, Georg-Simon-Ohm University Nuremberg, Fraunhofer Institute for Chemical Technology (ICT)

09:00 Registration and coffee

09:30 Nick Morley, Oakdene Hollins – Centre for Remanufacturing and Reuse
The Contribution of Product Life Extension to the Conservation of Strategic Metals

09:50 Christian Hagelüken, Umicore Precious Metal Recycling, Umicore Group Hanau
Recycling of Technology Metals – Opportunities & Challenges

10:10 Vittoria Fatta, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Rare Earth Recovery Through Hydrometallurgical Processes

10:30 Discussion

10:55 Networking break

Part IV Reducing waste in production and design

Introduction and chair: Mike Pitts, Sustainability Manager, Chemistry Innovation KTN

11:10 David Peck, University of Delft
Company Awareness and Responses to Critical Raw Materials in Product Design

11:30 Hywel Jones, Hallam University at Sheffield
What's in My Stuff: A Science and Art Based Approach to the Public Awareness of the Elements in Consumer Technology

11:50 Sophie Thomas, ThomasMatthews
Design that is fit for purpose and fit for the future

12:10 Matthias Koller, Federal Environment Agency (UBA)
Core Strategies for Enhancing Resource Efficiency

12:30 Discussion

12:55 Mike Pitts/David Gardner, Chemistry Innovation and Environmental Sustainability Knowledge Transfer Network
Concluding remarks

- Areas for collaborations
- Knowledge gaps to address
- Opportunities
- Next steps

13:10 Networking Lunch

14:10 End of workshop

Appendix C: Case studies

The RSC and UK Science and Innovation Network are grateful to participants for supplying the following case studies.

Case study 1
Graphene

Karl S Coleman
Durham University and
Durham Graphene Science Ltd, UK

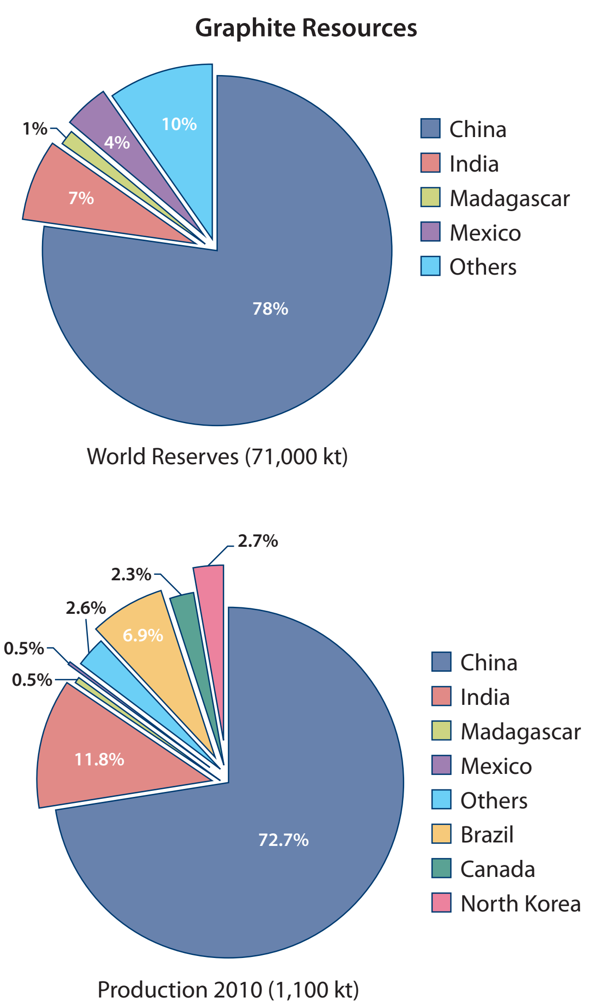
Graphene is a single-layer of graphite and is the newest member of the nanocarbon family, which includes carbon nanotubes and fullerenes. The two-dimensional single-layered continuous network of hexagonally arranged carbon atoms gives rise to exceptional and often unsurpassed electronic, mechanical and thermal properties. Graphene exhibits a high carrier mobility[13] (approaching 200,000 $cm^2V^{-1}s^{-1}$) and saturation velocity making it a promising candidate for future high-speed electronics and radio-frequency applications.

Graphene transistors with intrinsic cut-off frequencies beyond 100 GHz (double that of silicon) have already been achieved.[14] Aside from the interest in the unique electronic properties, graphene has exceptional strength with mechanical properties rivalling that of carbon nanotubes with a Young's modulus of 1 TPa and a tensile strength of 80 GPa,[15] which exceed the values obtained for high tensile strength steel. The thermal conductivity of graphene is high with values up to 5300 $Wm^{-1}K^{-1}$ recorded,[16] which is almost three times the value of diamond.

Energy storage in graphene is also exceptional (with values of 90Wh/kg reported) and could soon rival lithium ion batteries.[17] Owing to these exceptional properties we could see graphene application in new generation electronic components,[18] conducting inks,[19] energy-storage materials such as capacitors and batteries,[20,21] polymer nanocomposites,[22] and optically transparent conducting thin films.[23] It has even been widely suggested that graphene could eventually replace silicon in electronics, indium tin oxide (ITO) in transparent conducting displays, carbon fibre in composite materials and carbons found in capacitors and batteries.

The biggest challenge facing graphene is the availability of the material. So far the majority of the investigations into graphene and its properties are conducted on samples that originate from graphite.[24] Top-down graphene samples are obtained either by micromechanical cleavage of graphite or by oxidation and thermal expansion of graphite to graphene oxide which can then be chemically reduced.[25,26] It is also possible to exfoliate graphite by extensive sonication in solvent systems with surface energies that match that of graphite.[27,28] Whilst the micromechanical and solvent exfoliation methods are reliable and produce good quality graphene they are generally very time consuming and labour intensive and difficult to scale-up. The oxidation methodology suffers from the obvious disadvantage that graphene is converted to graphene oxide which does not have the same electrical and mechanical properties of graphene. These properties are only partially restored upon chemical reduction back to graphene. However, the biggest issue that the area could face if the obvious production issues are solved is the fact that graphite is a limited resource and is on the EU list of 14 critical raw materials (http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm).

The figure below shows the world graphite reserves (data according to the US Geological Survey) which stand at 71,000 kt, and the production rate which was at 1,100 kt in 2010. If graphene were to find its way to market in batteries, capacitors, composites or conducting inks, applications that would require large amounts of graphene material, the figure for the production of graphite could increase dramatically. Researchers are already looking for alternative methods for sustainable graphene production to reduce resource dependency on graphite. One promising method that essentially converts ethanol to graphene has been developed and is in the early stages of commercial development (www.durhamgraphene.com).



Source: U.S. Geological Survey, Mineral Commodity, Jan 2011

Fig 1.1

The demand on graphite resources for electronic devices has become less of an issue, as the fabrication of graphene transistors is moving away from exfoliated graphite. This is driven by the need to be at a wafer-scale. Although device performance is complex and depends on the interaction of graphene with the substrate and other electrode material, to move to wafer-scale it is necessary to use graphene films that can be grown over large areas. This can achieved by thermal desorption of silicon from single crystal silicon carbide wafers,[29] or chemical vapour deposition (CVD) of methane/hydrogen on copper foil.[30]

An area of great significance is the potential ability of graphene to replace indium tin oxide (ITO) in display screen technology and new generation photovoltaic devices. The main advantage being, as well as a high level of transparency across a large area of the electromagnetic spectrum, it is highly flexible unlike ITO. Currently technology is being commercialised by Samsung to use graphene in displays. However, as in the transistor case, it is desirable to use graphene grown over large areas. Graphene from the CVD of methane/hydrogen on copper can currently fulfil this role. However, with the difficulty associated with removing the graphene from the underlying metal foil and the transfer to a display plastic, it may be that other methods are sought which could involve graphene from graphite, or preferably graphene obtained from a sustainable process.

Case study 2
Recovery of phosphorus from sewage sludge ashes

Christian Adam
BAM Federal Institute for Materials Research and Testing, Berlin, Germany

Phosphorus is essential for all life forms and cannot be substituted in its functions, eg, for intracellular energy transfer (ATP) or storage and expression of genetic information (DNA, RNA).

Together with nitrogen and potassium, it is one of the macro-nutrients that is urgently required in agricultural food production. Phosphorus fertilisers are mainly produced from rock phosphate which is a limited resource. Existing rock phosphate reserves could be exhausted in the next 100 years.

The gradual depletion of the exploitable phosphorus reserves leads to more environmental stress and higher fertiliser prices. The major phosphate rock reserves are located in Africa and China whereas Western Europe is totally dependent on imports.

In order to safeguard limited resources and to become more independent of the complex phosphorus world market, European scientists, in particular, are investigating possibilities to recover phosphorus from waste flows. Of course this must be environmentally friendly and safe for the food chain. Wastewater is the most important waste flow for phosphorus recovery. In Germany, the theoretical potential in waste water is around 70,000 tonnes of phosphorus annually. The major part (about 90%) ends up in the sewage sludge and nearly half of it is used in agriculture or landscaping. However, the direct agricultural use of sewage sludge is controversial because it is a sink for pollutants in the waste water treatment plant. It also contains - besides heavy metals - a diverse array of organic pollutants. Therefore, the incineration of sewage sludge has become more common in the last ten years and accounts already for around 53% (approximately 1.1M tonnes) of the total sewage sludge disposal in Germany today, with an upward trend.

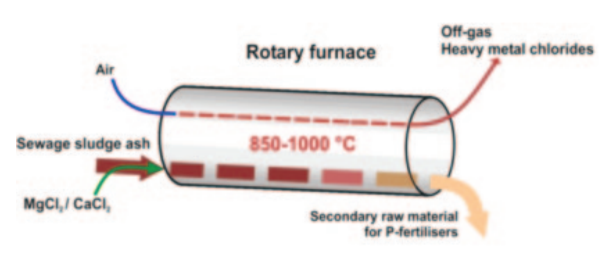


Fig 2.1

The ashes from mono-incineration facilities contain high mass fractions of phosphorus with 5-10 w-% P and are suitable for recovery purposes. Intense research was carried out at BAM Federal Institute for Materials Research and Testing, together with European partners within the framework of different European projects (EU-FP6-SUSAN, EU-FP7-SUSYPHOS), which focused on the development of technical processes that transform sewage sludge ashes into marketable and safe fertilisers. A thermochemical process was developed for the treatment of sewage sludge ashes to: i) remove heavy metals; and, ii) transform phosphates into bio-available mineral phases. Magnesium chloride is added to sewage sludge ash and the mixture is thermally treated in a rotary kiln at 850-1000°C for approximately 20 minutes retention time. Volatile heavy metal chlorides are formed, evaporated and separated via the gas phase in this process.[31] At the same time, bio-available magnesium and magnesium-calcium phosphates are formed.[32] The thermochemically treated ash is a suitable P-rich raw material for the production of fertilisers. The technology was already demonstrated in technical scale (capacity of 300 kg/h). The company OUTOTEC GmbH is currently planning the first industrial plants.

Case study 3

Recovery of scarce metals from end-of-life photovoltaic modules

Franz-Georg Simon and Wolfgang Berger
BAM Federal Institute for Materials Research and Testing, Berlin, Germany

Photovoltaics (PV) is a promising technology for renewable energy sources. In recent years the annual production of PV modules has been growing steadily reaching a total capacity of over 50GWp installed within the EU in 2011. Thin film technology (cadmium telluride CdTe or copper indium diselenide/disulphide CIS) is growing in importance due to its low production costs and the low energy and materials demands during production. However, the prices for the rare materials indium and tellurium will continue to increase. With the expected strong rise of the demand for thin film PV modules, recycling of indium and tellurium will become more important in the future.

Within the EU-LIFE project RESOLVED (Recovery of Solar Valuable Materials, Enrichment and Decontamination)[33] the feasibility of sustainable photovoltaic thin film module recycling by means of wet-mechanical processes was demonstrated by BAM Federal Institute for Materials Research and Testing, together with industry partners First Solar Inc and Deutsche Solar AG. Today, recycling of CdTe thin film modules, if they are recycled at all, is done by using chemical processes with hydrogen peroxide and sulphuric acid. The wet-mechanical treatment demonstrated in the RESOLVED project is an alternative and a new approach to the PV recycling with a minimum use of chemicals.

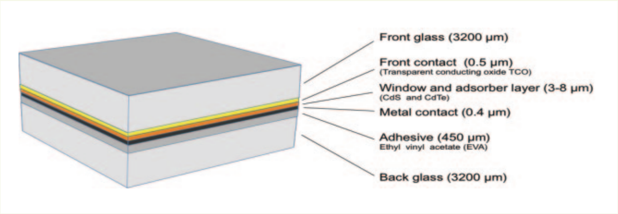


Fig 3.1

The semiconductor layers (CdTe or CIS) are encapsulated between two glass plates. To recover the valuable films the module has to be dismantled. The semiconductor layer can be removed by vacuum blasting. Vacuum blasting is a special blasting technique using vacuum instead of air pressure which is gentler to the glass surface than sand blasting and is typically used for edge treatment during module production. The blast material can be a wide range of conventional materials (eg, corundum, glass beads, etc.). The products are then handled by flotation to separate the semiconductor material from the blasting agent. Flotation is a wet-mechanical processing technology widely used in the mining industry to concentrate ores or separate minerals from coal.

The last steps are the enrichment of the valuables and the purification of the metals. The production of semiconductors for PV applications requires extremely high purities of the input materials, ie, 99.999%, usually called 5N. Waste treatment processes do not yield raw materials of 5N quality, and neither do natural resources, which means that they have to be processed in order to obtain pure materials. The concentrate from flotation is used as a raw material for the production of PV semiconductors. This closes the recycling loop.

A Life-Cycle-Analysis (LCA) proved that the recycling strategy, which includes module blasting and wet mechanical separation and enrichment, has clear environmental advantages in comparison with the production from virgin natural resources.

Case study 4

High-tech recycling could contribute significantly to an increased supply of technology metals

Christian Hagelüken,
Umicore AG & Co KG, Germany

Recycling opportunities

Access to raw materials and resource efficiency are at the forefront of the EU political debate and recycling is part of the solution to many strategic objectives. Recycling addresses resource scarcity and enhances security of materials supply, while contributing to energy efficiency and lower environmental impacts. Moreover, recycling offers investment, innovation and employment opportunities in the EU.[34]

In the framework of the Raw Materials Initiative, the European Commission identified a number of metals considered specifically critical from a European perspective. These 'technology metals' comprise many precious and special metals. They are contained in End-of-Life (EoL) products such as PCs, laptops, mobile phones, cars, rechargeable batteries and automotive catalysts. As such, this growing 'urban mine' provides a potential significant source of supply. For example, annual global sales of mobiles phones and computers account for about 20% of palladium and cobalt mine production, automotive catalysts require some 50% of the world mine production of platinum group metals (PGMs), and LCD screens account for about 80% of world primary production of indium. While the concentration in a single device (eg, a mobile phone) is usually very low, it is the leverage of millions and billions of devices on the market which makes them important.

For the eco-efficient recovery of technology metals from complex fractions such as circuit boards, batteries or catalysts, large scale, high tech processes are required. Umicore operates such an integrated metals smelter-refinery at Hoboken/Belgium (fig 4.1), where in total 19 different metals are recovered from annually over 300,000 tonnes of various complex feed materials. The recovered metals comprise the precious metals gold, silver, platinum, palladium, rhodium, ruthenium and iridium, the base metals copper, nickel, lead and tin, but also a number of specialty metals such as antimony, arsenic, bismuth, cobalt, gallium, indium, selenium and tellurium. Besides relevant fractions from end-of-life products, other main input streams to the plant are residues and side-streams from non-ferrous metals smelters, such as slags, slimes, flue dusts, etc.

While in most cases the value of the precious metals forms the economic trigger to ship recycling materials to Umicore, the sophisticated metallurgical flowsheet of the operation makes it possible to recover in addition many of the base and special metals which accompany the precious metals in the feed materials. Moreover, in addition to the 'universal flowsheet' capable of dealing with a large variety of feeds and metals, recently dedicated processes have been installed at Hoboken to treat high grade residues from manufacturing of thin film PV-cells as well as to recycle rechargeable batteries (Li-Ion and Nickel Metal Hydride). With the latter process it also became possible to generate concentrates of lithium and rare earth elements, which can be outsourced for final metal recovery.

Fig 4.1 Umicore integrated metals smelter-refinery at Hoboken/Belgium

Recycling challenges

Despite significant legislative efforts to establish a circular economy in the EU, today the majority of these valuable resources are lost due to insufficient collection, partly inappropriate recycling technologies (also within Europe), but above all due to large and often illegal exports streams of EoL products towards regions with poor or inappropriate recycling infrastructures. In the latter case a treatment by backyard 'recyclers' in developing countries leads not only to low metal recovery rates but also to dramatic impacts on health and environment. Hence, despite very efficient metallurgical recycling processes at the end of the chain, capable of recovering well over 95% of the precious metals, the bottom line recycling rate from electronics today is only 15% for gold and 10% for palladium.[35]

In order to realise the full potential of recycling in the EU, with a particular focus on critical metals, a holistic system approach is needed including an integrated and well organised recycling chain. As such, recycling success depends on each step of the chain (fig 4.2) as well as on the optimisation of the different interfaces. The overall recycling efficiency is determined by the weakest step in the chain, i.e. a highly efficient metallurgical recovery process is useless in case collection is poor or high losses occur during pre-processing.

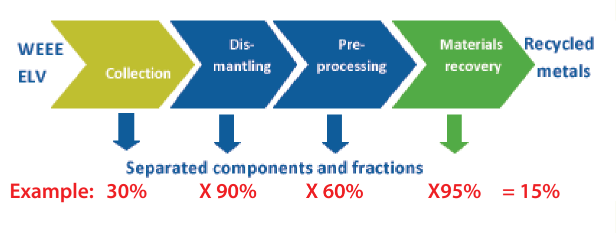


Figure 4.2 Recycling success chain

In this respect, pre-processing (the manual and/or mechanical separation of various components/fractions from products) plays a crucial role, since it has to steer various fractions into the most appropriate final metallurgical recovery steps. If done in the wrong way or with substandard systems, significant losses especially of precious and special metals will occur. The final step in the recycling chain is the recovery of substances in a quality that enables their use in new products and the Umicore case study given above shows what is possible already today.

Recycling requirements

As shown, in real life most EoL fractions do not enter such state-of-the-art facilities. A sustainable solution can only be achieved in a holistic system approach, covering adequate product design and business models, ensuring a comprehensive collection as well as appropriate dismantling/pre-processing, and creating transparent, well monitored flows of EoL products. To be successful, the following conditions must be met.

- Technical recyclability of the material or metal combination as a basic requirement.
- Accessibility of the relevant components to steer these into adequate materials recovery.
- Economic viability, whether intrinsically or externally created.
- Collection mechanisms to ensure a comprehensive collection of EoL products.
- Entry into the recycling chain and remaining therein up to the final step.
- Optimal technical and organisational set-up of this recycling chain.
- Sufficient capacity along the entire chain to make comprehensive recycling happen.

Efficiently recycling our EoL products today is insurance for the future. Effective recycling systems would thus make a significant contribution to conserving natural resources and securing sufficient supplies of (critical) metals. It would further mitigate price volatility and limit the climatic impacts of metals production.

Case study 5
German Resource Efficiency Initiative

Werner Maass
Association of German Engineers Centre for Resource Efficiency (VDI ZRE), Germany

The German Resource Efficiency Initiative highlights resource efficiency as a business opportunity and helps companies implement resource efficiency such that the payback period is short enough to provide an incentive.

According to the Federal Statistical Office, the cost of materials and raw materials accounts for 44% of all internal costs in an average German production company. The cost for energy accounts for 2% and those for staff, 18%.

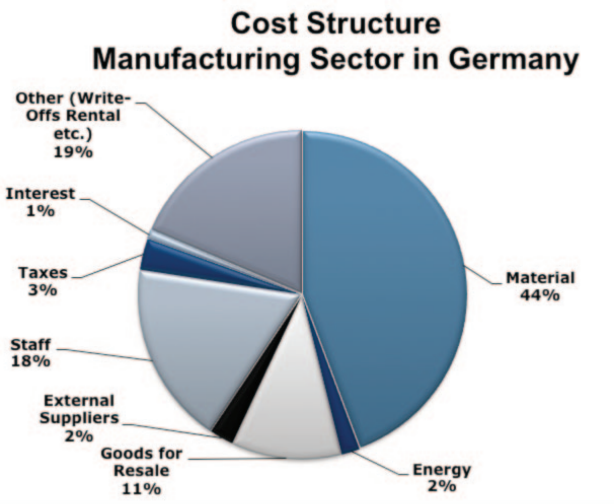


Fig 5.1

German industry, therefore, is quite resource efficient compared with other economies. While resource efficiency has improved by 40% since 1998, there is still an enormous potential for cost reduction especially in SMEs. Cost reduction by reducing materials costs will improve the competitive position and secure the production capacities in Germany.

Since 1979, the Federal Environment Agency is funding eco-innovation and environmental technology transfer within Germany. Several German states (Laender) like North Rhine Westphalia, Baden Wuerttemberg, Rhineland Palatinate and Bavaria have supported resource efficiency in SMEs since 1998 through different schemes. In 2005 the Federal Government launched a similar funding scheme for resource efficiency at national level.

There are currently four main routes to resource efficiency.

- **Business processes:** Most SMEs have a lot of room for efficiency in different sub-processes like logistics, production planning, accurate procurement and knowledge about the Total Costs of Ownership (TCO). There is mostly low investment needed and the payback times for small resource efficiency investments are less than 12 months.
- **Improvements in the production process:** A medium-sized casting company enhanced its casting process by introducing new capsulated production lines which significantly improved quality and minimised the typical finishing work. The company benefits from a 50% reduction in tooling and 65% reduction in energy costs.

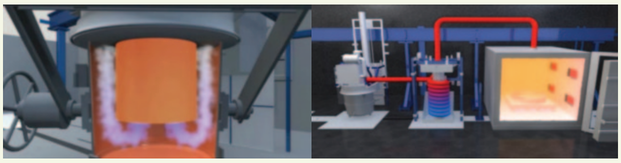


Fig 5.2

- **Technological change:** A metalworking company changed their entire production process by applying different manufacturing technologies. As a result, the company saved 80% in high priced material and 30% of the whole operation costs. Technology changes have a high resource efficiency potential, but payback times are longer. Another consideration is that technology changes result in challenging requirements for the company. If companies fail to meet those, they could go bankrupt.
- **Taking a holistic approach:** A machine-building medium-sized company in Baden Wurttemberg implemented a new production process including highly sophisticated logistics and energy supply based on renewables. This company applied a continuous quality cycle with all employees and is able to produce more heating and electricity than it consumes. www.resource-germany.tv

Fig 5.3

The Association of German Engineers Resources Efficiency Center (VDI ZRE) was founded in 2009 as a subsidiary of the Association of German Engineers (VDI), the largest engineering and scientific association with some 150,000 individual members). The VDI was founded in 1856 and offers about 1,900 valid VDI guidelines describing the state of technology. The VDI ZRE's activities are funded by the German Federal Environment Ministry.

German manufacturers face an increase in the cost of resources, including material, raw material and energy costs, which represents 44% of their internal costs. In response, investments in greater efficiency are required and the VDI ZRE supports this by offering a range of different tools, information and activities.

Fig 5.4

Several projects and studies illustrate that approximately 20% of the material costs can be reduced through resource efficiency activities with a payback time of around two years. Manufacturers benefit from greater resource efficiency by increasing their profits and competitiveness and by reducing CO_2 emissions.

Case study 6
Aerospace, Defence, Security and Space Trade Organisation

Andy Clifton
Sustainable Development & HS in Design
Rolls-Royce Corporate HS&E, UK

At a system level, companies within the Aerospace, Defence, Security and Space (ADS) sector are moving towards service-based business models. This brings significant benefits to resource efficiency as not only does it provide a company with stewardship over the materials embedded within its products (helping it to maximise reclamation at product end of life), but, at a more fundamental level, it decouples material throughput from profit.

At a process level, the ADS sector has, for some time, been investing in *near net shape manufacturing technology*, which means that components are manufactured to closely resemble the finished products, (laser deposition/powder bed and hot isostatic pressing and sintering for example). This reduces both initial material demand and the quantity of waste generated. The drive towards this is primarily due to the high value materials the sector needs to use in order to provide the high levels of safety and performance demanded by its customers. However, there is also a growing concern with regard to the long-term sustainability of the supply of these materials, in particular those available from a small number of supply routes.

Where waste is generated, there are a wide range of recycling initiatives that maintain the quality of materials for the ADS sector and support their retention within the supply chain. These initiatives range from agreements with material suppliers to return manufacturing waste for reprocessing to aerospace grade material, to the development of industry supported disposal best practices (such as those produced through the Aircraft Fleet Recycling Association).

Due to industry expansion, recycling initiatives will not address 100% of the ADS sector's material demands and a supply of virgin material will be needed for the foreseeable future. That said, recycling is a key element from a resource efficient industry and, perhaps more importantly, a sustainable supply chain. This is particularly true if recyclate can be collected, reprocessed and then reused within the confines of a given geographic region (eg, Europe). With this in mind, take-up of recycled material within the ADS sector is not really an issue, in that it will be considered wherever it is safe to do so (the high quality demands of some aerospace components mean that recycled material cannot be used, or only used in small percentages).

Substitution is always a possibility when it comes to efficient use and sustainable supply of resources. However, substitutes are often highly application dependent and where one material may once have provided a material solution to a wide range of requirements; its substitute may only address a handful of those applications (eg, substitutes for hexavalent chrome). At a national and international level, there should also be some consideration given to the effect that such application-specific substitution may have on the total market for the substituted material. For example, if a substitute is found for a large volume user of a material (eg, the automotive industry), consideration should be paid to the potential effect that the switch to this alternative may have on other users (eg, aerospace). If the large volume manufacture significantly reduces its demand for a material, will there be sufficient value in supplying a small volume manufacturer to justify keeping the business running?

A particular area where substitution is being looked at in the ADS sector is in substituting metal for composites. The main drive for this switch is the weight-saving it offers, which in turn offers a reduced carbon footprint of ADS products in use. The problem with using composites is that they are much more difficult to recycle than metals. Does the benefit of the weight saving offset the decrease in recycling rate or does more effort need to be spent in improving recycling technology of composite first?

In summary, Europe plays a leading global role in the ADS sector. To maintain that position, there is a growing need to consider the long-term material resource requirements of this industry sector and how the national and continental resource supply, and reuse/recycling infrastructure, is set up to meet those requirements.

Case study 7
Remanufacturing

Nick Morley
Oakdene Hollins, UK

The Centre for Remanufacturing and Reuse is run by Oakdene Hollins Ltd and provides certification and environmental impact assessment services to organisations active in the area. It was first established as a pilot programme under the UK Department for Environment, Food and Rural Affairs (DEFRA) Business Resource Efficiency and Waste (BREW) programme.

Oakdene Hollins is a sustainable innovation and resource management consultancy, working for both public and private sector organisations. Over the last ten years, Oakdene Hollins has carried out extensive research into remanufacturing activities in the UK; the work under the BREW programme provided an in-depth examination of remanufacturing and reuse options and how they can contribute to an economy of sustainable production and consumption in the UK.

The first year of the centre's work for BREW (2006/07) comprised a pilot programme that collected evidence as a basis for further intervention in year two. Over 16 product groups were examined in order to determine their remanufacturing potential and produce intervention strategies.

Remanufacturing is an industrial practice which can be summarised as: 'A series of manufacturing steps acting on an end-of-life part or product in order to return it to like-new or better performance, with warranty to match'. Often, remanufacturers take the opportunity to upgrade the products from old to current performance standards of energy efficiency or productivity. This is one way that they can be differentiated from simple repair items and other end-of-life treatments.

Caterpillar Inc (CAT) is a world class OEM and remanufacturer of heavy machinery, with a centre for excellence in Shrewsbury in the UK. For 80 years, CAT has been building the world's infrastructure and, in partnership with its independent dealers, is driving positive and sustainable change on every continent.

Caterpillar is a technology leader and the world's largest maker of construction and mining equipment, diesel and natural gas engines and industrial gas turbines. With its head office in Peoria, Illinois, CAT is a truly global company; CAT products can be seen at work in over 200 countries worldwide. Its products include track-type tractors, hydraulic excavators, backhoe loaders, motor graders, off-highway trucks, wheel loaders, diesel and natural gas engines and gas turbines.

Many other manufacturers use CAT engines and systems to power their products.

Caterpillar began its remanufacturing business in 1972 following demand from its customers in the US for high quality, low cost replacement engines for their on-road truck fleets. Remanufacturing at CAT has come a long way since then, and now all CAT customers can take advantage of a broader range of remanufactured products in most areas of the world. Always on the lookout to enhance its global position and capabilities, CAT acquired The Perkins Engine Company in 1997, taking over Perkins' facilities in Peterborough, Stafford and Shrewsbury.

Keen to improve access to remanufactured equipment for their European customers, CAT refocused the Shrewsbury operations to remanufacturing in 2004 making it one of four European sites. Shrewsbury is now the remanufacturing centre of excellence for Europe, Africa and the Middle East.

Remanufactured CAT products are purchased by large haulage fleet operators, defence organisations such as the UK Ministry of Defence, rail providers, mining and quarrying firms, agricultural users, construction firms and marine users

Caterpillar's motto for its remanufacturing division is 'as good as new, as strong as ever'. Every remanufactured product that leaves the factory has been through a stringent quality test procedure, often having been passed along the same production line as a new product. This is backed up by a full warranty, the same as is issued with a new product.

When a customer purchases a remanufactured part from CAT it is delivered to them in a reusable container, for which they pay a deposit. When returning a worn part ('core'), customers are expected to use this container. The Shrewsbury site has reduced its wooden packaging waste by 70% using this system, reducing costs and making sure worn parts arrive undamaged. The customer also pays a deposit which is refunded upon receipt of their worn part (provided it is complete and has no extreme damage). The worn parts are then sorted at Shrewsbury and given a basic visual inspection. Some parts will be remanufactured on site and others will be shipped to facilities elsewhere.

In 2005 CAT's global remanufacturing operation reused 43 million tons of core material. This means that by remanufacturing rather than recycling, CAT has prevented 52 million tonnes of CO_2 emissions entering the atmosphere. It also means that other associated waste due to raw material extraction has been substantially reduced.

Case study 8
What's in My Stuff?

Hywel Jones
Materials and Engineering Research Institute (MERI) Sheffield Hallam University, UK

In today's developed societies we all own an unprecedented amount of 'stuff' and we live in a society where most of us are so removed from the reality of how all that stuff we consume is created. Nothing is more representative of this than our ownership and attitudes to the mobile phone.

The increasing demand for smartphones in developed societies and the huge market for mobile phones in developing countries have led us to ask the following questions:

- Do you know what's in the stuff you use every day?
- Do you know where the chemical elements in your things come from, how they're extracted and how sustainable is their use?
- How often do you discard something rare and precious without even realising it?

The project engages with the public and explores the relationship between people and their gadgets. In doing so it hopes to raise public awareness of the issues around critical materials supply, recycling and sustainability.

'What's in My Stuff?' has used an interdisciplinary approach, bringing together scientists and artists in order to explore ways of engaging in a dialogue with the users of technology, seeking their views, informing them of the key issues and acting as a catalyst for changing attitudes.

These are some of the key facts which are being communicated to end users.

- In 2011 1.6 billion mobile phones were manufactured, containing an estimated 56 tonnes of gold worth an estimated £1.9 billion.
- Every hour of every day over 1,000 mobile phones are replaced in the UK.
- There are an estimated 90 million unused mobiles lying idle in UK households in which the precious metals alone are worth more than £150 million.
- In 2008 only an estimated 3% of mobile phones were recycled.
- Mobile phones contain up to 40 of the chemical elements (almost 45 % of those available to us).
- China controlled, at peak, >98% of global production of the 'rare earth' elements vital for the function of modern technologies such as electronics, wind turbines and electric cars. In recent years it has cut back on both production and export to the rest of the world.

The project has used a number of interdisciplinary approaches to engage the public including:

- pop-up field laboratories for phone deconstruction and analysis including electron microscopy to explore the internal landscapes of mobile phones at high magnifications;
- the making of unique jewellery pieces by Maria Hanson using deconstructed mobile phones;
- the construction of a thought-provoking work of art based on the elements found in a mobile phone (Element Rings by Maria Hanson);
- the creation of image galleries, key facts, activity reports and links to key data on the project website www.whatsinmystuff.org

Throughout the events the level of public knowledge about the 'ingredients' of a mobile phone have been tested, along with attitudes to ownership, sustainability, recycling, durability, and emotional connections to technology. It has become clear that very few end users of technology have any knowledge of what goes into their gadgets, both in terms of the engineering components and in terms of the chemical elements.

The surveys and activities carried out have begun to reveal some of the human factors that are acting as a barrier to a more responsible approach to the ownership of consumer technology. These include: an 'out of sight, out of mind' attitude; emotional/sentimental attachment to devices; a lack of knowledge of why it is important to recycle and how to do it; and, data security issues. All of these human factors can be positively influenced by the kinds of participatory events this project has been piloting.

An audience survey conducted during a public museum exhibition of Maria Hanson's Element Rings provided the following data:

- 80% of pop-up laboratory participants had more than one unused mobile phone at home, while 11% had 5 or more;
- before seeing the Element Rings exhibit 60% of respondents either did not know or had never thought about what was in their phones;
- 94% of those surveyed said that the exhibition had made them more aware of at least some of the chemical elements within their phones;
- 52% of those viewing the exhibit said they would now be more likely to recycle or trade in their old phones (30% indicated that they already did this).

The personal and emotional response to the exhibit was recorded:

Love it/beautiful/great	34%
Interesting/makes you think/ learnt something/stimulating	36%
It needs to be more prominent/ more impact/bigger	16%
Funny/enjoyable	6%
Great for raising awareness	8%

The project is now looking for funding to run larger, more ambitious projects on a national scale, including further jewellery exhibitions, fully equipped field laboratories and public lectures.

Additional information is available at www.whatsinmystuff.org

Case study 9
UK National Industrial Symbiosis Programme

Rachel Lombardi
International Synergies Ltd, UK

International Synergies Limited devises and manages facilitated industrial symbiosis programmes around the world, as well as providing support to in-country partners to establish and develop their own programmes.

Its flagship programme is the UK National Industrial Symbiosis Programme (NISP) that has been delivering triple bottom line sustainability benefits (including resource efficiency) through industrial symbiosis for almost 10 years with the tagline 'connecting industry, creating opportunity'. The company's international portfolio includes assisting in the set up and implementation of industrial symbiosis projects in Romania, Hungary, United States, China, Mexico, Brazil, Turkey, South Africa and Slovakia.

The majority of NISP's (UK) 15,000 members are micro-entrepreneurs, and small to medium-sized enterprises (SMEs). The programme also engages closely with research through universities and institutes. By facilitating introductions to non-traditional partners, practitioners identify uses for organisations' underused resources which may be traditional by-products and waste (materials going to landfill) or underused assets, expertise, waste CO_2 or low-grade steam. NISP has been recognised by the Organisation for Economic Cooperation and Development (OECD) and the EU as an eco-innovation exemplar, fostering process, product and market innovation. A few examples follow.

The EU Waste Framework Directive 2008/98/EC often classifies waste streams generated by manufacturing processes involving metals as hazardous waste which is a particular burden for SMEs. In what follows NISP demonstrates how its facilitated introductions brings process innovation to market, keeps materials circulating in the economy for longer, and reduces hazardous waste and associated costs for the SMEs.

A company* that recovered silver (Ag) from medical X-ray films was unable to proceed with its existing process after a change in film production technology. Through NISP the company was introduced to researchers within the industrial symbiosis network who developed a change in process that enabled the company to process the new generation of films. This demand-led research was brought immediately into application, resulting in a process innovation that enabled the company to utilise its existing cost effective facility without expensive investment.

Another company* that recovers precious metals and includes lead in their incineration process had suffered in the economic downturn, and was not using its full capacity. Through the NISP network, non-traditional feedstocks were identified whereby innovative technical modifications to a recovery furnace resulted in the plant achieving full capacity.

Process innovation is not limited to materials that can be sent to landfill (hazardous or otherwise). One large company*, a manufacturer of ammonia products (fertiliser) produced low grade heat and carbon dioxide as by-products of its process: both are suitable for growing fruit and vegetables in greenhouses. NISP practitioners facilitated an introduction between the ammonia manufacturer and what is now the largest tomato grower in the UK, resulting in the companies investing in a greenhouse co-located with the fertiliser plant, and pipes bringing the CO_2 and waste heat directly from one to the other to enable year-round commercial tomato growing at a reduced cost. The €17million inward investment created 65 new jobs and reduced CO_2 emissions by 12,500 tonnes.

It is unclear how far along the path to sustainability industrial symbiosis can get us. But it is delivering impacts today in many countries across the globe and has garnered the attention of the EU and OECD, the International Finance Corporation and the World Bank. At all levels in Europe – local, regional, national and international – industrial symbiosis is increasingly being seen as a strategic tool for resource efficiency as well as economic development, green growth and innovation.

*Company details are confidential due to the nature of the business.

Case study 10

Resource policy – an interdisciplinary action area

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A resource efficiency policy is a challenging and inter-disciplinary action area which is now off to a start with ProgRess – the German Resource Efficiency Program – on a national level and at the EU-level as part of the schedule for a resource-efficient Europe. An innovative sustainable resource policy does not have to be completely 'reinvented'. Despite great complexity, it can learn from other policy areas and use the experience of other countries. Because of its significant and achievable cost saving effects alone, resource efficiency policy that connects the strategies for abiotic and biotic materials, water, energy and space, is the upcoming major issue of environmental and economic policies.

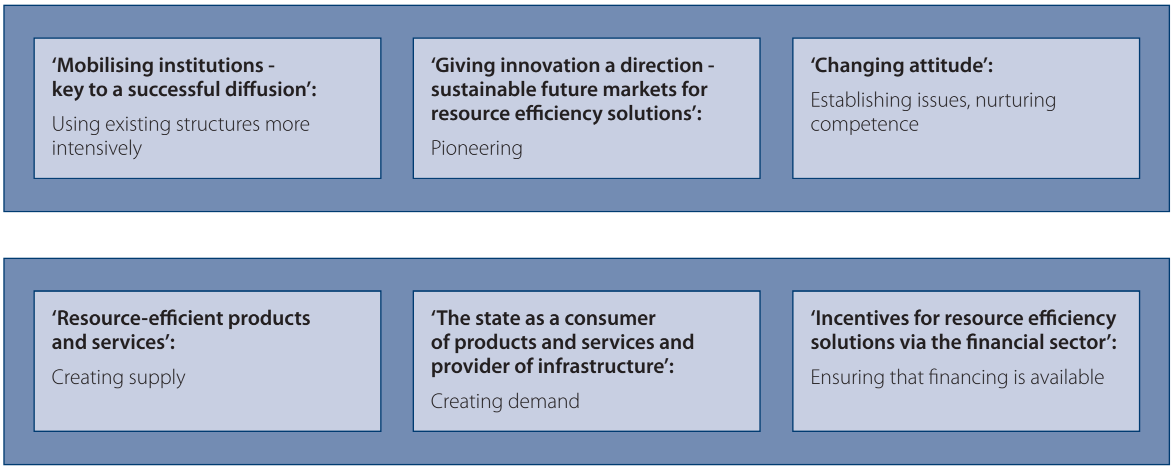
In the context of the challenges described, a resource efficiency policy must advance the redesign towards a resource-saving, sustainable economic system with corresponding structures of production and products. Reliability – based on political consensus – and scientifically sound mitigation goals serve to guide long-term investment decisions for structures of production and infrastructure with long investment cycles (such as mobility and energy systems).

Resource policy is an interdisciplinary task that must be seen in an international context and must involve global aspects. As a resource-poor country, Germany is both a major importer of resources and a major exporter of solutions for the resource efficiency of products and services. On a physical level, the global aspects become apparent because of the impact of imported raw materials (such as the transfer of the environmental impact onto the supplier countries) or international waste exports. Helping to shape the flagship initiative on resource efficiency as part of the EU-2020-strategy launched by the European Commission in January 2011, and the schedule of autumn 2011 based thereon, is just as important as the technology and know-how transfer with emerging economies and developing countries as equal partners.

In order to choose suitable instruments from a wide range of alternatives, policy must focus its goals on core strategies. However, resources policy is a highly complex field with many factors and approaches, so there cannot be just a single policy instrument. Instead, it is important to choose a carefully crafted 'policy mix' with just the right instruments. That way, many barriers can be detected, various audiences can be addressed, and different players can be integrated as supporters. Prioritised core strategies also provide an interdisciplinary orientation and help with the public communication of this new policy field. The core strategies and the instruments chosen for their implementation are selected according to the following criteria:

- The core strategies need to reach the key target groups and address those of their action areas that are key to resource efficiency.
- The 'policy mix' chosen needs to finance itself overall to avoid additional burdens on public budgets.
- The instruments allocated to the core strategies for the initial phase should build on what already exists, so that implementation can succeed as quickly and easily as possible. For this purpose, existing structures should be expanded (if they already include resource efficiency), or opened up for the topic.
- The number of selected instruments must be kept at a manageable level. In addition, the instruments chosen need to focus on key areas.
- The instruments should be chosen so that they can be flexibly adapted to new developments and changing conditions, or may be adjusted to combine well with other instruments which may become necessary later. Once the resource issue is more broadly established, and initial successes emerge, the 'policy mix' and the policy instruments must be further developed.

Core strategies and the objectives they pursue in Germany



'Mobilising institutions - key to a successful diffusion':
Using existing structures more intensively

'Giving innovation a direction - sustainable future markets for resource efficiency solutions':
Pioneering

'Changing attitude':
Establishing issues, nurturing competence

'Resource-efficient products and services':
Creating supply

'The state as a consumer of products and services and provider of infrastructure':
Creating demand

'Incentives for resource efficiency solutions via the financial sector':
Ensuring that financing is available

Fig 10.1 (Source: Kristof/Hennicke 2010)

The core strategy 'Mobilising institutions - key to a successful diffusion' makes it clear that we need strong institutions that promote and spread resource efficiency. The basic requirement is to expand and to better network the existing national stimulus and consulting programs around the issue of resource efficiency (eg, KfW program, Go Inno). Institutions that act as 'caretakers' are important because of their initiation and support functions and their practical implementation support on site. By expanding and qualifying the existing pool of consultants with the help of active stakeholders (such as VDI ZRE, demea, Effizienz-Agentur NRW, PIUS network) and by supporting regional structures and networks, the necessary technical know-how and adequate implementation assistance can be provided to businesses.

Case study 11

Company awareness and responses to critical materials in product design (research update April 2012)

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This update highlights the first results of ongoing research that was first reported to the conference entitled *Resources that Don't Cost the Earth – Encouraging European Solutions and Collaboratio*n, at the British Embassy, Berlin, 1-2 December 2011.

The goal of this research is to assess the effects materials criticality has on technological companies in the Netherlands and what kind of implications that could have for industrial design engineering.

Participating companies were chosen from the membership of the Dutch industry association FME-CWM which brings together more than 3,000 companies in the metal, plastics, electronics and electrotechnical industry and related sectors. A total of 30 companies participated.

From the research the following conclusions can be drawn:

- **Three quarters of businesses (to a greater or lesser degree) are familiar with the concept of critical materials:** Just over three quarters of the companies surveyed are familiar with the concept of critical materials under different names. The majority of companies face problems with the purchase of raw materials or components. Nine of the 30 companies follow critical materials developments closely; 15 companies are doing that to a lesser degree, whilst six companies do not feel critical materials is an issue for them.
- **Critical materials certainly do play a role in the Dutch technology industry as a whole:** Out of a total of 35 different critical elements on the EU list, 12 are used by the companies. The best known are cobalt, magnesium, graphite, and tungsten (as an alloying element for steel) and neodymium as an element in permanent magnets. In addition, the companies name another 14 materials as critical, but they are not on the EU list. These include nickel, chromium (both as a part of stainless steel), copper and plastics constituent materials. Critical materials are usually included in intermediate goods and parts. In only 7% of cases, is a critical raw material purchased in a 'pure' form. In 52% of the cases it was included in base metals or semi-finished products and 36% in bought-in components. This reflects the position of Dutch industry in the production chain, which is mainly dependent on imports of already processed materials, semi-finished products and components. This makes the Netherlands, of course, more sensitive to supply disruptions in critical materials.
- **Problems with critical materials are supply chain problems:** As many as 24 of the 30 participating companies, or 80%, have, over the last five years encountered problems with the delivery of critical materials. These are materials on the EU list, but also materials named by companies themselves as critical. In many cases the supply chain was sensitive to disruptions and there are very few critical material alternatives available. With the advent of the critical materials phenomenon, the purchasing departments in these companies have been given a new challenge to address. Only a handful of companies are working on alternatives through changes in product design and production. The R&D departments are even less involved in critical materials.
- **Forecasts for the next five years:** Twenty-two companies expect that the role of critical materials will increase. The reason for this is directly linked to the expected production growth of businesses, increasing use of electric cars and e-bikes, and the increased application of high-tech electronics and appliances. The general expectation is that the prices of critical materials will increase.
- **Threats and opportunities:** Sixteen companies expect to experience no problems with critical materials as a result of their good supply chain management and new (external) developments in the field of recycling and production of critical materials. In contrast, six of the 30 companies do expect problems in the next five years, either because of their small size (they do not have power over their suppliers), or because there is insufficient time and/or resources to innovate alternative products.

Seven of the 30 companies see a great deal of opportunity resulting from critical materials. A better controlled and understood supply chain can be a competitive advantage over other companies. In addition they see critical materials as an incentive to develop smart materials and cradle to cradle design solutions.

Survey conclusions

This initial survey among Dutch companies is primarily intended as input for follow-up discussions about materials and their critical role in the Dutch technology sector. The best approach for this discussion is to have all stakeholders are involved – government, industry and knowledge institutions. The researchers laying the ground for such discussions should make note of the following recommendations:

- Create and maintain a situation tailored for the Dutch list of critical materials. The EU list of critical materials covers only a part of the critical materials in the Dutch context. For a specific Dutch policy in Critical Materials a tailored list is needed. Furthermore, many companies want to follow developments in the field of critical materials in order to prevent problems, and/or find opportunities.
- Ensure the supply chain for the Dutch technological industry is robustly maintained. Problems with critical materials in the short-term are largely preventable by improving the usually fragile supply chains of Dutch companies. The improved mapping of the various supply chains should make them more robust. In particular improvements can be found by addressing issues such as single sourcing.
- Encourage innovation in companies in the field of alternatives. Changing the product design and the use of alternative materials in response to problems with critical materials is currently rarely carried out. Over the long-term, companies that do undertake these approaches will find this gives them a very clear advantage. Stimulating innovation in companies into the field of alternatives can turn a disadvantage for the Netherlands (where there are few natural resources) into an advantage.

Case study 12
When Resources Were Easy: A Historian's View

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Our time is not the first that tries to grapple with the challenges of resource scarcity. In fact, people have rarely *not* worried about it: even in Victorian Britain, Lord Kelvin worried about the coming end of the age of coal in a famous speech of 1881. So it should not come as a surprise that the *Resources that Don't Cost the Earth* workshop was full of allusions to history. In times of uncertainty, turning to history is a natural reaction, and certainly a wise one. When it comes to resources, the modern era offers plenty of fodder for thought.

Few things would be more naïve than dismissing the current wave of depletion fears as a mere repetition of a familiar theme. Since the publication in 1972 of the Club of Rome's 'Limits to Growth',[36] people in the Western world have heard numerous warnings of impending scarcity; but that mirrors first and foremost an enduring concern.

Throughout history, resources have rarely been 'just there'. Getting minerals out of the ground, or agricultural commodities from fields to consumers, is a tough business with all sorts of contestations: strikes, wars, breakdowns of technologies and traffic links. In the twentieth century, there were really only some 20 years when resources were relatively 'easy', namely from the early 1950s to 1972/73, when the collapse of the Bretton Woods system and the 1973 oil crisis rocked the world. The experience of 'easy' resources was a memorable one, however, and it seems that deep down our society is still dreaming of a chance to somehow return to that age. In its hunger for ever more stuff, and the elusive hope for cheap, no-frills supplies, Western societies are uncomfortably reminiscent of addicts who got the first shot for free.

Those who see the 'Limits to Growth' as a classic 'false environmental alert' are therefore missing the point in at least three ways. First of all, the book's data was not from its authors or the Club of Rome: information on remaining reserves, including oil reserves, came from the literature. Second, the book was not primarily about predictions, and certainly not authoritative ones: at its core, it was a reflection about the folly of exponential growth. Third, the warning and the ensuing oil price shock brought consequences, as it spurred users and researchers into action. All over the world, we see industrialists and engineers scrambling to increase the efficiency of resource use after 1972/73, effectively ending two decades of waste and neglect. Much of what we have achieved in terms of resource efficiency loops back to reactions to that wholesome shock.

The 1970s are just as remarkable for what they did *not* do. They did not reinvigorate European mining. Quite the contrary, the decline of European resource extraction is plain in retrospect. Many small and medium-sized mines were closing, either due to international competition or because of a toll that was no longer acceptable in advanced, post-industrial countries. Digging large holes in the ground requires a broad consensus to tolerate grave consequences and enduring scars in the land, and that consensus was gone for all means and purposes by the 1970s. Those who are currently dreaming about a boom of primary mining in Europe should take note.

Global commodity chains replaced local suppliers, and now appear so much as a given that Chinese restrictions on rare earth metals resonate globally. It is quite clear that globalisation was also an externalisation of material and immaterial costs that Western countries were no longer willing to tolerate. For instance, the Mountain Pass mine in California, the key domestic source of rare earth metals in the United States, curtailed its operations in 1998 and closed in 2002, mirroring a general decline of mining in the wake of environmental protest. But they also had a second, less obvious effect: global supply networks perpetuate the era of the 'faceless resource'. As commodities meander around the globe, they lose any hint as to their origin.

Once more, it is crucial to note that this anonymity is a recent invention. Until the middle of this century, resources still had a face: people talked about English coal, Swedish iron ore, or Persian oil. It was post-World War Two globalisation and consumerism that made these localisations a fading memory. One name change may serve as an illustration: in 1954, the Anglo-Iranian Oil Company changed its name to British Petroleum.

In the internet era, the age of the faceless resource is nearing its end. Tellingly, we have become alert to coltan, an obscure mineral if ever there was one, from the Central African country of Congo, one of the least traveled places on the globe. Moving resource extraction beyond the purview of Western publics no longer works, and local resistance is mounting even in non-democratic countries. Formerly resource companies simply moved on when things became inhospitable, but that strategy is facing limits nowadays. The world may not be running out of resources, but it is running out of places where resources are easy to get. We no longer have a China to spare.

What all this suggests is that the current wave of concern may miss the deeper change that we are witnessing in our time. When it comes to resources, an era is drawing to a close: the age of the easy, faceless commodity. Historically speaking, we are back to normal. Resources are finite, precious, they have a history, and they have a price in more than just monetary terms. However, resources are also amenable to wise management, and generations of experts and businessmen have learned a lot in this respect. We can benefit from their experience, and all the better when we face up to our preoccupations. Resource-wise, the 1950s and 1960s were too good to be true, and far too good to allow an encore.

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