SUSTAINABLE USE OF NATURAL RESOURCES

Science and Implementation Plan

Security of Supply of Mineral Resources (SoS Minerals) Research Programme 2012–2017

EXPERT GROUP

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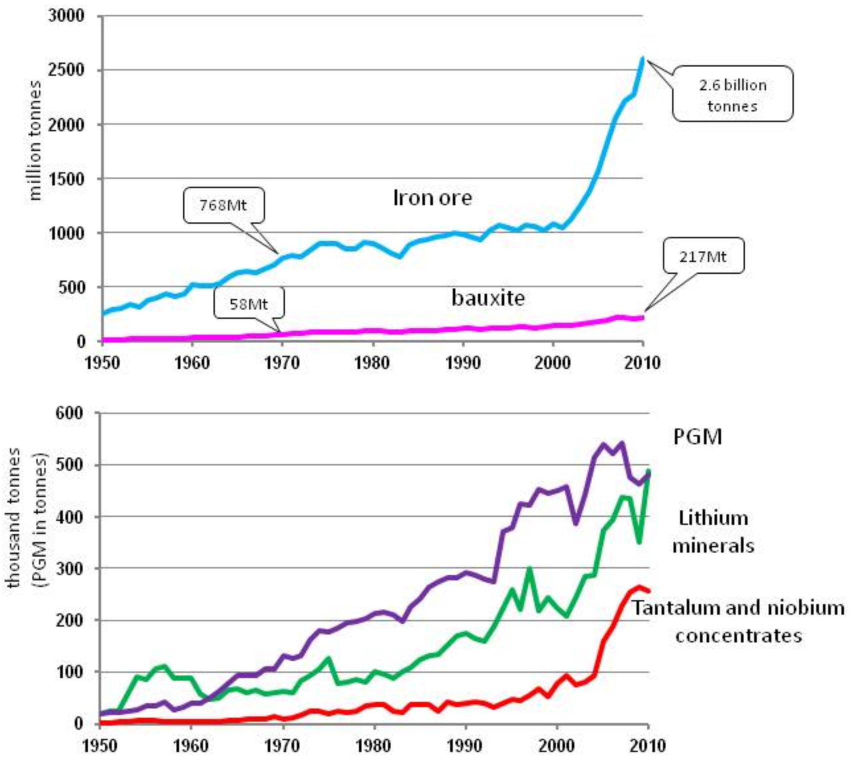
Watermark is a neodymium magnet (NdFeB) as used in hybrid cars and many other environmental technologies

INTRODUCTION

The consumption of most minerals and related metals has increased steadily since World War II, and it is likely that demand will continue to grow in response to the burgeoning global population and the inexorable spread of prosperity across the world especially in the BRIC economies (Figure 1). At the same time, global action to protect the environment and to mitigate and adapt to increased atmospheric CO_2 is demanding significant changes in the way we generate and use energy. These include an increase in the amount of energy produced from renewable resources, including wind and solar; a growth in the use electric and hybrid vehicles; and increasing energy efficiency of electronics in both industrial and domestic use. However, the environmental technologies and applications that will allow for cleaner energy and more efficient energy usage depend on a range of raw materials – referred to herein as **E-tech elements**, e.g. cobalt, lithium, niobium, Platinum Group Metals (PGM), Rare Earth Elements (REE), indium – that are primarily provided by mining. This **SoS Minerals** initiative will provide the research capacity and evidence base to reduce, not increase, supply risk of these minerals and elements, governed by the imperative to decrease environmental impact.



Data from British Geological Survey

Figure 1 Historical metal and mineral production graphs showing the increase in demand for raw materials

The variety and amount of E-tech elements needed in the future is difficult to predict accurately, given rapid developments of environmental technologies, but already some elements are in short or disrupted supply for various reasons: scarcity at economically recoverable grades; difficulty of recovery; environmental impacts of mining; political/strategic control of exports; and rapid growth in demand. Furthermore, the EU is almost wholly dependent on imported supplies, from a small number of sources, and this is currently compounded by low substitutability and recycling rates (commonly < 1%). Unlike the major industrial metals, such as iron and copper, only in the last two decades have widespread applications for many of the E-tech elements become important. Historically, therefore, less attention has been paid to their exploration, mining, processing, recycling and substitution.

The global **Security of Supply** of E-tech elements can be significantly improved by locating new resources, better understanding the abundance and distribution of E-tech elements in existing ore deposits and by improving the processes that recover them from the primary ore. Recovery of the E-tech elements will require new mines, or new processes at existing mines, and this will generate additional environmental impacts, including greenhouse gas emissions. Thus, in order for the E-tech elements to be environmentally beneficial, in production as well as use, the full impacts of their exploitation must be understood. In many cases, E-tech elements are by-products of more abundant commodities within an ore body; therefore, reducing the environmental impact of extracting the entire ore body is needed.

In order to maintain a secure, environmentally and socially sustainable supply of E-tech elements, research is needed now to improve our understanding of how they are transported, concentrated and deposited into potentially exploitable resources. This will lead to a broader and larger resource base, resulting in a greater and more flexible supply of raw materials. In addition, research is needed to quantify and mitigate the environmental impacts of the exploitation of new and existing resources of E-tech elements, both as primary and by-products. Although the technologies they support may be environmentally benign, the production of those technologies may contain significant "embedded" negative environmental impacts. Improving extraction and processing is vital to the sustainability of environmental technologies.

To tackle the challenges presented, the **SoS Minerals** Expert Group has developed the two over-arching goals as:

Goal 1	**Understand E-tech element cycling and concentration in natural systems;**
Goal 2	**Understand how to predict and mitigate the environmental effects of extraction and recovery of E-tech elements.**

The programme will deliver evidence that will inform decision makers on ways to minimize the impact on the environment of exploring for and exploiting E-tech element resources, as well as ameliorating the extraction process. This will be achieved through coordinated research projects targeting novel research into high priority E-tech elements, their environmental context and wider implications of their extraction and recovery. The programme will develop an interdisciplinary community building on UK strengths, linking to industry and related international initiatives.

THE NERC CONTEXTAND MECHANISMS

The **SoS Minerals** programme aims to deliver research to address some of the key challenges within the NERC Sustainable Use of Natural Resources (SUNR) strategic theme, one of the seven science themes within the NERC Strategy 'Next Generation Science for Planet Earth' (2007-2012)[1]. For the SUNR theme, the strategic objective is to provide the science to optimise the use of renewable and non-renewable natural resources whilst living within the Earth's environmental limits. To deliver this, investment in science is needed to bring together and advance understanding of the entirety of processes and consequent outcomes of natural resource use on terrestrial, freshwater and marine systems and on feedbacks to the atmosphere.

Following initial discussions with industry, academia and learned organisations by the SUNR Theme Leader, NERC's Science and Innovation Strategy Board has identified *Mineral Resources: Science to Sustain Security of Supply in a Changing Environment* — **SoS Minerals** — as a targeted area for research investment, and NERC Council has approved £7 million for this purpose. The Theme Action Plan[2] provided the two high-level science challenges, which are central to the development of the initiative:

- Challenge 1 Quantify the processes mobilising and concentrating mineral associations supporting environmental technologies;
- Challenge 2 Predict the environmental impact of low carbon extraction/recovery of strategic minerals.

The action is also closely related to other NERC Research Programmes such as **Resource Recovery from Waste: Challenges for the Health of the Environment**[3]

The **SoS Minerals** programme will run for five years and the funds will be allocated in two phases. Phase 1 (~£0.5m) will involve pump-priming lasting around 18 months and consist of a parallel series of Catalyst Grants along with development of a Network that will be international in scope. It is anticipated that the second phase will evolve from the Catalyst Grant activities, and consist of interdisciplinary research teams, working in partnership with industry and enabling international exchange of research ideas, personnel and activities. The direct involvement and contribution of industrial partners will be a *sine qua non* for the **SoS Minerals** programme.

STRATEGIC CONTEXT

Introduction

As outlined above, environmental technologies[4] are an attractive route to reducing carbon dioxide emissions to the atmosphere and developing the global green economy. However, these new technologies are significantly and rapidly increasing our use of a range of elements (e.g. Co, Li, Nd, Te, In, Nb) – the E-tech elements – which, coupled with limited availability of material for recycling, are generating a new set

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[1] http://webarchive.nationalarchives.gov.uk/20120703105236/http://www.nerc.ac.uk/about/strategy/ngscience.asp

[2] http://webarchive.nationalarchives.gov.uk/20120703112514/http://www.nerc.ac.uk/research/themes/tap/documents/tap-natural-resources-p3.pdf

[3] http://www.nerc.ac.uk/research/funded/programmes/waste/

[4] These include: *Future energy supply* (e.g. REE, Co, PGEs); *Energy conservation* (e.g. REE, In, Ga); *Environmental protection* (e.g. REE, PGMs)

of technological, commercial, political and environmental challenges concerning their supply. These challenges are recognised to be international in dimension and have generated a number of high-level investigations into the relationship between economic importance of an element or mineral and its vulnerability to supply disruption (e.g. Figure 2 – the "EU14")[5,6,7].

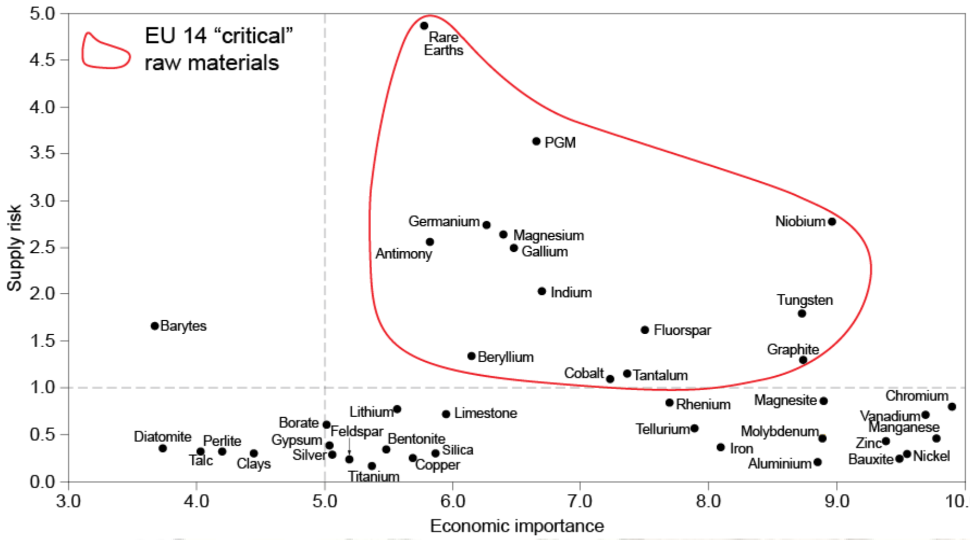

Figure 2. Diagram illustrating the 14 "critical" raw materials identified by the European Union

These studies have identified a range of elements/minerals that may be at risk of supply disruption. These have been variably termed critical/strategic metals/minerals/materials. Though there may be some debate over what is the correct terminology to use and the preferred methodology for assessing supply risks, all reports identify these as a set of elements that include the lanthanides (Rare Earth Elements), some speciality and transition metals, plus several semi-metals in groups IV, V and VI of the periodic table (Figure 3).

On a broader scale, refining ores generates a globally important carbon footprint, e.g. over 4 % of global greenhouse gas emissions arise from iron ore production and refining[8]. Innovative and cross-disciplinary science is needed to address the environmental challenges that will result from increasing mineral exploitation in a low-carbon context. The **SoS Minerals** programme will build in the rising demand for E-tech elements into strategies to foster the environmental optimization of extraction methods to limit the risks of a consequent rise in CO_2 emissions. It would be self-defeating if winning the elements cost more environmentally than their subsequent utility.

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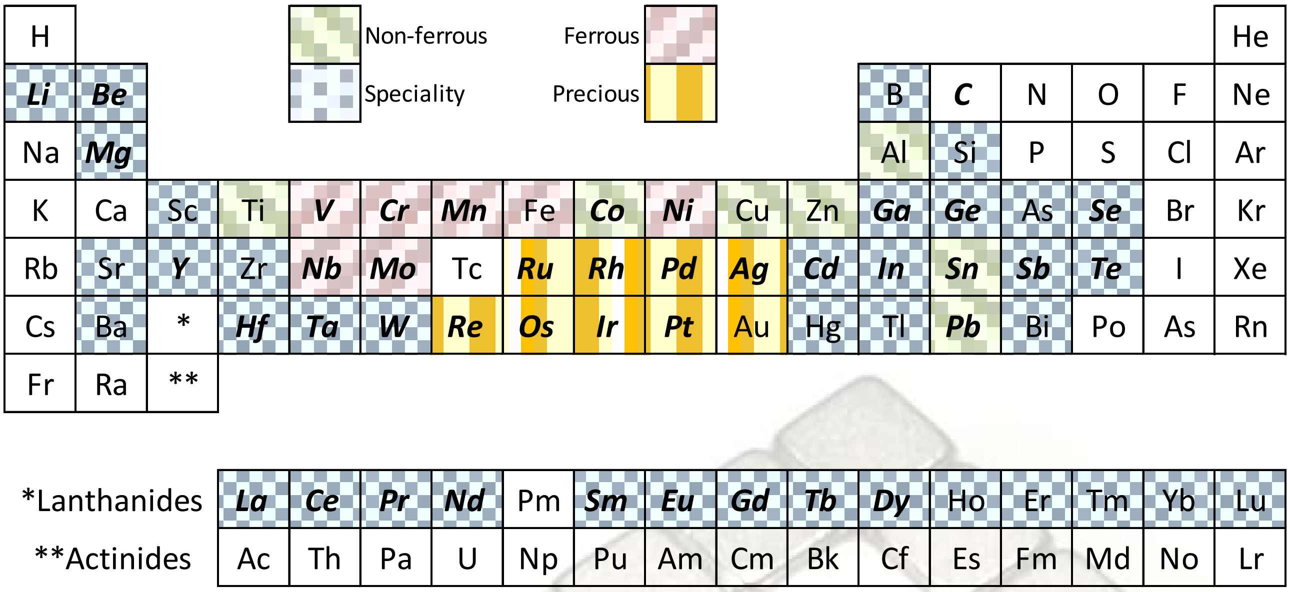
[5] Critical Metals in Strategic Energy Technologies, The Institute for Energy and Transport of the Joint Research Centre (JRC) of the European Commission published 2011

[6] Critical Metals Strategy, US Department of Energy, published 2011

[7] EU Raw Materials Initiative COM(2008)699, published 2010

[8] IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B.,O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.



Non-ferrous
Ferrous
Speciality
Precious

H																	He
Li	***Be***											B	***C***	N	O	F	Ne
Na	***Mg***											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	***V***	***Cr***	***Mn***	Fe	***Co***	***Ni***	Cu	Zn	***Ga***	***Ge***	As	***Se***	Br	Kr
Rb	Sr	***Y***	Zr	***Nb***	***Mo***	Tc	***Ru***	***Rh***	***Pd***	***Ag***	***Cd***	***In***	***Sn***	***Sb***	***Te***	I	Xe
Cs	Ba	*	***Hf***	***Ta***	***W***	***Re***	***Os***	***Ir***	***Pt***	Au	Hg	Tl	***Pb***	Bi	Po	As	Rn
Fr	Ra	**															

*Lanthanides	***La***	***Ce***	***Pr***	***Nd***	Pm	***Sm***	***Eu***	***Gd***	***Tb***	***Dy***	Ho	Er	Tm	Yb	Lu
**Actinides	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Figure 3. Periodic table showing E-tech elements [in bold and italics] from *Critical Metals in Strategic Energy TechnologiesCritical Metals Strategy* and *Critical Raw Materials for the EU*.

Innovative and cross-disciplinary science is needed to address the environmental challenges that will result from increasing mineral exploitation in a low-carbon context. NERC's **SoS Minerals** programme has been developed to elucidate and meet these challenges.

Transport and concentration of E-tech elements in the Earth's crust have not received the attention of the major industrial metals: their geoscientific research base is relatively low, and the environmental impacts of their exploitation poorly known. In addition, reduction of environmental footprint, including becoming more energy and resource efficient, is a key aim for the wider mining community. These present significant science challenges and two Science Goals emerge:

1. **Understand E-tech element cycling and concentration in natural systems;**

2. **Understand how to predict and mitigate the environmental effects of extraction and recovery of E-tech elements.**

All funded projects will be required to address both goals.

RESEARCH AREAS

The following science priorities and themes were developed by the Expert Group[9] assembled by NERC to refine the high level programme research goals and focus the science into a coherent plan for the Research Programme.

Science priorities

The EU study (Figure 2) identifies fourteen raw materials, commonly known as the EU14, whose supply is defined as critical. However, the EU14 were only a snapshot in time and not definitive – there are other significant studies of supply risk that identify a different set of elements[5,6]. It is certain that these lists will change within the timescale of the programme; the next evaluation of the EU14 is currently underway.

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[9] Prof A. Boyce, Scottish Universities Environmental Research Centre (Chair), Mr A. Gibbon, Minerals Industry Research Organisation, Prof. H. Glass, University of Exeter, Mr G. Gunn, British Geological Survey, Prof. B. Johnson, Bangor University, Dr S. Roberts, National Oceanography Centre, Dr D. Smith, University of Leicester, Prof. M. Tibbett, Cranfield University, Prof. Frances Wall, University of Exeter, Prof. B Yardley, University of Leeds.

Moreover, the high-level investigations[5,6,7] into where elements and minerals may fall in the *economic importance* and *supply vulnerability* space integrate a number of drivers, including environmental criteria. Thus, to ensure that the correct science opportunities are identified, societal and geopolitical aspects need, to some extent, to be isolated from “criticality” and “strategic” assessments. In addition, a principal science goal from the defining Theme Action Plan is to *quantify the processes mobilising and concentrating mineral associations supporting environmental technologies.* Thus, it is important to go beyond the strict limits of the EU14, because some elements, such as Te, Se, Li and V, which are not currently on the EU14 list, but lie close to the criticality border, underpin important environmental applications such as photovoltaic and portable power technologies. Increasing use of these (e.g. Figure 1) means they have strong potential to be in short supply in the near future.

The Expert Group thus examined E-tech elements in terms of their importance for use in environmental technologies and applications (e.g. wind turbines, photovoltaic cells, fuel cells) against knowledge gaps in how they are mobilised and concentrated in the Earth’s crust. This identified four quadrants of opportunity to quantify the processes mobilising and concentrating E-tech elements (Figure 4A). As noted above, this list is not simply a repetition of existing lists, but one that has scored importance to environmental technologies. Thus, the prioritisation exercise identified Te, Se (photovoltaics) and Li, V (portable power) as raw materials to be included, whilst excluding Sb, Be, Mg, W, Ta, Ge and fluorite, which have less direct environmental applications.

In terms of understanding how existing and emerging technologies for extraction and recovery of E-tech elements, and associated ores, affect the environment (Science Goal 2), a similar exercise was undertaken by looking at the scope for minimising the environmental impact of resource extraction (including industrial metals) and tensioning this against knowledge gaps to identify the appropriate quadrants of opportunity (Figure 4B). This enables research to be focussed on the technologies that will have the greatest environmental benefits. Large environmental benefits are likely to be achieved by integrated research on E-tech elements and associated major industrial metals (Figure 4C).

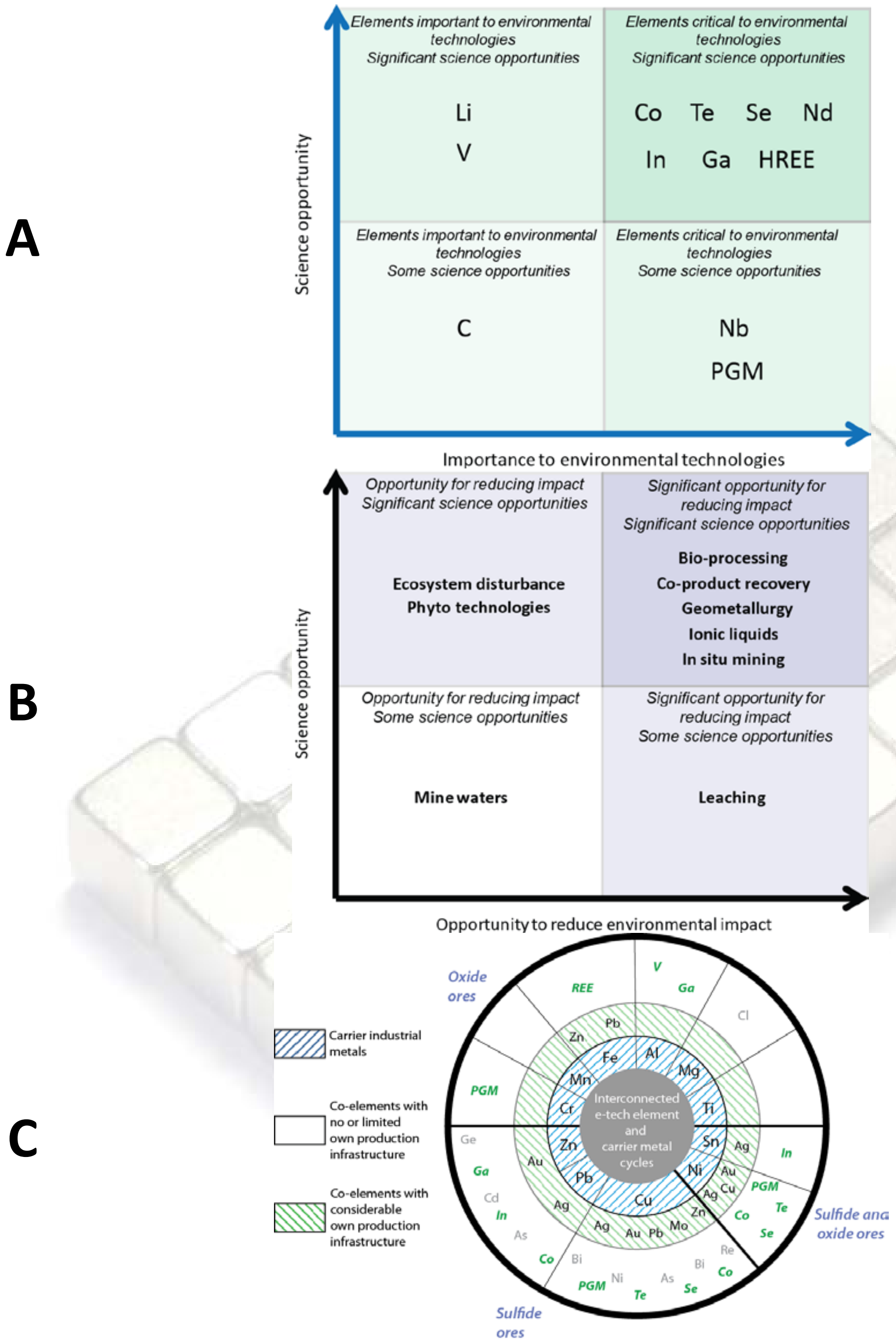

Figure 4. A: Qualitative assessment of science opportunities and importance to environmental technologies related to E-tech elements considered to be in scope for this programme; B: Qualitative assessment of science opportunities and potential for environmental optimisation of resource exploitation and processing —The strategic science focus of the programme is towards elements and technologies in the upper-right hand quadrant of each Boston Diagram; C: Major industrial metal and E-tech element [in green and italics] associations[10].

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[10] Based on Reuter Wheel (Reuter, MA et al.. 2005, The Metrics of Material and Metal Ecology, Harmonizing the Resource, Technology and Environmental Cycles; Elsevier: Amsterdam, The Netherlands; Verhoef, EV et al., 2004, Process knowledge, system dynamics and metal ecology. J. Ind. Ecol. 2004, 8, 23-43.)

Science goals

1. Understand E-tech element cycling and concentration in natural systems

Goal 1 is about discovering how natural processes concentrate the E-tech elements.

Research focus

The focus will be on the E-tech elements prioritised in Figure 4A. However, it can include major industrial metals as part of a close physical and genetic association (Figure 4C), provided this is not the major focus of the research. Moreover, these provide the links to Science Goal 2, where the largest gains are likely to be achieved through minimising the impacts of the associated major industrial metals.

Examples of areas where there are science opportunities include:

- How E-tech elements are mobilised, where they occur and why some (e.g. In [Zn], Te [Cu], Co [Cu], Ga [Al]) are associated with specific major industrial metals
- Low temperature (<450°C) systems where natural analogues are most likely to inform lower-energy mineral exploitation and recovery
- E-tech element concentration processes in the Earth's Critical Zone[11] including biological processes
- Selective enrichment of E-tech elements in mantle-derived magmas
- The role of extreme fractionation for enriching E-tech elements in a limited number of evolved igneous rocks
- Behaviour of volatile elements in crustal scale systems
- Enrichment processes and element abundance in non-traditional sources (e.g. as a by-product from fossil fuel deposits or from submarine deposits)

The list above is not intended to be exhaustive, and other science opportunities that address the programme's overall goals will be considered.

2 Understand how to predict and mitigate the environmental effects of extraction and recovery of E-tech elements

Goal 2 is about the environmental science associated with E-tech element exploitation technologies that will (i) enable the downstream development of low-carbon and low-water mineral resource extraction while (ii) sustaining provision of key ecosystem services.

Research focus

The focus will be on the key technologies identified in Figure 4B. All mineral resource exploitation has environmental implications. Life-of-mine and post-mining ecosystem disturbance can have severe on- and off-site environmental effects including acid generation, metal contamination and biodiversity loss, often resulting in a critical loss of ecosystem services and depletion of natural capital. There is a need to be able to quantify and repair these environmental impacts. This is not an environmental impact assessment, but is about understanding the relationship between the mineral resource exploitation and consequences for ecosystem function. That is, resource extraction disturbs the stability and flows between ecosystem

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[11] NRC (National Research Council) (2001) Basic Research Opportunities in Earth Science. National Academy Press, Washington, 154 pp

components and, depending on the level of resilience and disturbance to the system, its return to normal functioning may be delayed. Where critical ecological biotic or abiotic thresholds have been crossed, recovery of ecosystem function will require intervention. Therefore, there is a need to develop an understanding that predicts and describes how mineral extraction from different types of mineral deposits affects ecosystem function and its possible routes to restoration.

Examples of areas where there are science opportunities include:

- Mineral–fluid–microbe interactions in the near surface that inform *in situ* mining technologies
- Comprehending fluid flow and reactive transport of E-tech elements in mining sites
- Ecosystem disturbance from terrestrial and marine extraction of E-tech elements
- Geological controls on the physico-mechanical properties of ores and their matrix rocks to environmentally optimize the extraction process
- Application of ionic liquids to extraction of E-tech elements
- Natural systems as potential analogues for low carbon mineral processing
- Ecosystem reconstruction

As for Goal 1, the list above is not intended to be exhaustive, and other science opportunities that address the programme's overall goals will be considered.

GLOBAL PERSPECTIVE

The Security of Supply of E-tech elements can be significantly improved by locating new resources and the research needs to be focussed where the deposits occur. Thus, the scope of the proposed action will be global. In addition there may be synergies and added value of working with particular industries at a variety of mining and exploration sites. Hence, the development of research sites at relevant mines will be encouraged by the programme.

The need to identify new resources of E-tech elements closer to the UK is justified from considerations of reducing carbon footprint. However, it is also important to improve our fundamental understanding of natural concentration processes for these elements. Where specific deposits provide unique opportunities to act as natural laboratories to address such fundamental science, then it will be important to take advantage of them regardless of location.

MULTI- / INTERDISCIPLINARY NEEDS

Promoting interdisciplinary working between different research and end-user communities will be fundamental to the Programme's success. Many aspects require expertise from a range of environmental sciences. For example, much progress has been made in recent years on bio-processing via understanding microbial interactions[12] and aspects such as reductive mineral dissolution have generic applications and mark a major breakthrough in bio-mining technology. Understanding these mineral–microbe fluid interactions will engage microbiologists, and some of the fundamental controls on element cycling will need input from theoretical chemistry (*ab initio* modelling). Potential applicants will need to be aware of the broad range of science that will be required for success.

There are clear synergies with other Research Councils, and there is the opportunity to interact with activities in EPSRC, BBSRC and ESRC. However, NERC science will need to be at the core of any project and

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[12] Rawlings DE, Johnson BD (2007) Biomining, Springer, 314p.

the key science aspects will be Earth system processes, natural analogues and environmental processes that inform and support mineral exploration / exploitation technologies and environmental accounting in a way that optimises the environmental outcomes and that aids in reducing, not increasing, supply risk.

It is envisaged that a key element of all Catalyst Grants will be to scope out the multi- / inter-disciplinary needs in order to tackle the science challenges detailed above that cross-cut research sectors. The Catalyst Grants will also bring researchers together from different disciplines to start building potential teams. In addition to our core support, the programme will welcome existing cross-disciplinary partnerships, and will work with other Research Councils to lever in expertise and funding.

RELATIONSHIP TO OTHER INITIATIVES

It is recognised that there are a number of initiatives in this area already underway or in planning and it is not intended that this programme will duplicate these efforts. Therefore, it is important to make the distinction between programmes with which the **SoS Minerals** aims to collaborate directly and those which are doing similar and/or relevant science with which the **SoS Minerals** programme can engage or align.

There are a number of initiatives currently underway in the European Union FP7 programme and in the design of its replacement, Horizon 2020. In FP7, there is a €17m project, ProMine. A component of this is to produce mineral deposits databases[13] at a range of scales. It is likely that there will be similar programmes in the future and the outputs from these will have particular relevance to Science Goal 1

NERC, ESRC and the Department for International Development (DfID) are co-funding a multi-disciplinary £40·5m research programme on Ecosystem Services for Poverty Alleviation (ESPA). The programme aims to deliver high quality and cutting-edge research that will deliver improved understanding of how ecosystems function, the services they provide, the full value of these services, and their potential role in achieving sustainable poverty reduction. Science Goal 2 has the potential to provide significant baseline information for valuing the mineral resources component of ecosystem services. Moreover, mineral resource development can have significant impacts in alleviating poverty in low income countries. Therefore, there are opportunities for **SoS Minerals** to interact with EPSA research initiatives.

PROGRAMME ACTIVITIES

Programme Timeline

Network launch	February 2013
Catalyst AO published	February 2013
Closing date for Catalyst Grants	April 2013
Assessment Panel for Catalyst Grants	June 2013
Catalyst grants awarded	July 2013
Catalyst grants begin	August 2013
Catalyst grants end	May 2014
Invitation to Research Grant submission	May 2014
Closing date for Research Grant applications	June 2014
Moderating Panel for Research Grant call	October 2014
Research Grants awarded	October 2014
Research Grants begin	January 2015
Research Grants end	January 2018

*This is currently subject to change.

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[13] ProMine Data Portal – http://promine.gtk.fi/index.php/news/128-promine-mineral-resource-database-goes-online, published 2012

Catalyst Grants

This programme will require researchers to collaborate across disciplines, and with industrial and international partners. The Catalyst Grants will bring researchers together to build potential research teams. Catalyst Grants are aimed at enabling researchers to develop realistic and relevant research partnerships and research strategies with the potential for significant national/international impact and to develop proposals. Catalyst Grants are not intended to support research projects, but may support some preliminary research activity. At the Catalyst Grant stage good interdisciplinary research ideas are more important than having whole interdisciplinary groups in place, or even identified. At this stage applicants are eligible to submit proposals that do not have all interdisciplinary collaborations in place at the outset, provided that applicants demonstrate how they will address this. Catalyst Grants may support the following kinds of activity:

- Evidence gathering, strategic reviews and research needs/impacts assessments
- Planning and hosting of themed "research challenge workshops" and research meetings
- Building appropriate research strategies, plans and proposals
- Bringing together working partnerships, collaborations and management mechanisms
- Developing leadership teams and management structures
- Negotiations with host institutions and outside funders
- Developing KE and communication strategies

The Announcement of Opportunity (AO) for the Catalyst Grant call will be released in February 2013 and close in April 2013. Proposals will be assessed by an expert panel, which will make recommendations to the Programme Executive Board (PEB) for funding.

Projects will be between £50k and £100k (80% FEC) and run for 9 months. There is a total of up to £500k for this round. Proposed projects start date must be no later than August 2013 and therefore will finish in May 2014.

Research Grants

At this stage, it is planned that the call for the main Research Grants will be a closed call, i.e. open only to those with funded Catalyst Grants. However, NERC reserves the right to open the call to further Expressions of Interest if the PEB decide that this is necessary. The research community will be alerted to any change of plan by August 2013 in order to provide sufficient time for preparation of full proposals.

Funds available for this round will be £6 million. It is expected that between 3 and 6 grants will be awarded. Projects will be no more than 3 years in duration and should begin by January 2015. There will also be a central fund of money for programme level Knowledge Exchange (KE) and coordination.

The Research Grant applications will be externally peer reviewed, including an applicant response stage and moderating panel. The moderating panel will make recommendations for funding to the PEB.

PROGRAMME MANAGEMENT

The roles and responsibilities of the groups are detailed below.

Programme Executive Board

The *Security of Supply of Mineral Resources* programme will have a Programme Executive Board (PEB). The PEB is the executive decision-making body for the programme and provides the overall strategic direction.

Science Coordination Team

The Science Coordination Team (SCT) will lead on developing and expanding the programme and manage a number of the day-to-day aspects, consulting widely with the academic community, stakeholders and end-users.

Management Team

The Management Team will be responsible for administering the programme. This team is run from Swindon Office. Activity will involve: coordinating the production and publishing of a Science and Implementation Plan and Announcement of Opportunities; administration of the grants process; day-to-day management of the programme. This group will report to the PEB. The Management Team may seek advice from others as appropriate.

Assessment Panels

Assessment panels will be assembled to undertake the assessment of Catalyst Grant proposals and to moderate the external reviews of the Research Grant proposals. They will consider both quality of the proposed activity and their ability to deliver the requirements of the programme. These groups will consist of national and international experts in the field, including a member of the NERC Peer Review College for benchmarking. These assessments will inform the PEB's decisions on the award of funding to deliver the programme vision. There will be a separate panel for assessment of each phase of funding, but overlap in membership is likely.

DATA MANAGEMENT

NERC requires that research programmes implement a data management scheme which covers practical arrangements during the programme and subsequent long-term availability of the data set. In line with the NERC data policy (http://www.nerc.ac.uk/research/sites/data/policy/), the data from the programme will be lodged with the appropriate NERC Designated Data Centre. NERC puts an obligation upon PIs to ensure that data management is undertaken in a suitable way. A well-structured identification system is essential for data collection and experimental sample labelling.

Individual proposals should state data collection plans, staff responsibilities and data quality as part of their Data Management Plans. Sufficient budget for this (suggested ca. 2.5%) should be written into grant applications. The funded project PIs (with assistance/guidance from the MT and PEB) will be responsible for agreeing the Programme's data management plan with the data centres and overseeing data management.

KNOWLEDGE EXCHANGE

Knowledge Exchange will facilitate the communication of the science delivered from this programme to a variety of users including policy makers and industry, and exchange of views and knowledge from these stakeholders with a view to achieving the paradigm shift required. There will be two levels of KE, at the project level through Pathways to Impact and at the programme level. Both levels will be expected to engage with the programme network (see below). KE is intrinsically linked to both the multi-/interdisciplinary partnerships and to associations with other investments.

For both programme and project level KE, it will be required to identify the target communities/stakeholders, consider how these various groups/individuals are likely to benefit from (or be affected by) the research, create a plan to engage with them which is appropriate and goes beyond communication, be directional, timely and happens early in the design stage.

At this early stage in the process, where the research scope is not yet fully defined, the optimal range of KE activities at the programme level is unclear. Once the Catalyst Grants are awarded it will be possible to define this more precisely. These plans will be finalised once the range of topics and number of Research Grants are known. It is clear, however, that this activity should support activities to stimulate innovation and new collaboration, avoid duplication of effort and allow effective project alignment and interaction. This will foster programme integration, achieve added-value and the production of high-quality deliverables.

Individual projects will be required to submit a Pathways to Impact plan as part of both the Catalyst Grant and Research Grant applications. For the Catalyst Grant application, pathways to impact activity is likely to be minimal but applicants should provide an indication of the plans that will emerge in the full Research Grant proposal and therefore assessment will be as *potential impact*.

KEY OPPORTUNITIES

Network

A research – industry network will be an essential component of **SoS Minerals**. The overall aim of the **SoS Minerals** Network will be to deliver the Knowledge Exchange plan that will:

1. develop a thriving, interdisciplinary scientific community undertaking research related to security of supply of minerals (as defined by the SoS Minerals Science Plan), and the environmental implications of exploiting these minerals; and

2. proactively engage the extractive industries, their supply chains, trade associations, consultants and end-users to inform and aid in accelerating the uptake of programme outputs into companies to significantly enhance their business performance.

To meet these aims NERC plan to fully fund the establishment and operation of the **SoS Minerals** network for the first year but will be looking to the network to secure other contributions, in-kind or cash, from other funding agencies and the private sector in order to grow, from its inception and throughout the five year programme (even beyond the initial five year period if the network becomes sustainable).

There are two main elements for the delivery of a successful Knowledge Exchange Network:

- availability of an efficient, flexible and reliable platform with effective ICT support, and
- management by a Network Director with a good knowledge of the whole subject area with the support of an efficient and effective support team.

Key stakeholders will include major multinational companies. Mid-tier producers and junior exploration companies will also be encouraged to join the Network. Networking with downstream stakeholders or end-users of E-tech elements, such as the energy, aerospace and communications industries, will also be encouraged. The research side will include the UK mineral deposit research community as represented by organisations like the Mineral Deposits Studies Group and relevant other special interest groups of the Geological and Mineralogical Societies. However, as the scope of **SoS Minerals** is global there will also be a need to include an international dimension. In this respect, organisations like the Society of Economic Geologists (SEG) and the Society for Geology Applied to Mineral Deposits (SGA) and the Institute of Materials Minerals and Mining (IOM3) will be key. **SoS Minerals** will encourage innovative and original approaches to understanding processes of metal mobility and concentration. To achieve this it will be essential also to reach beyond these traditional ore deposit research communities to include a wider range of innovative geochemists, engineers, biogeochemists and energy and ICT experts.

Industry collaboration and co-Partnerships

Industry and agency partnerships will be essential to the development and success of the programme leading to conceptual and technological advance with measurable environmental benefits.

Partnerships may include those with other Research Councils, industry/business, government agencies or departments etc. It is envisaged that industry partnerships will be at a variety of levels – from individual project participation and funding to contributions at the programme level. In addition to financial partnership, assistance could also be in the form of providing access to data, materials or a research site.

The UK-based global mining industry has stated aims to develop more effective, less intrusive exploration; more societally acceptable extraction techniques, and technological advances to recover deep, dispersed or dilute new deposits – all of which are well-aligned with the proposed **SoS Minerals** programme[14]. A key pathway to impact is pre-competitive collaborative research and development to bring new environmentally sensitive technologies to commercial feasibility.

Significant partnership funding (either financial or in-kind) for individual projects will be an expectation and an assessment criterion for the programme's large Research Grants. Furthermore, at a programme level, the programme management team will seek partnership funds, which will be used to enhance the overall Research Programme funding levels.

International collaboration and co-funding

Dedicated international activities are likely to include exchange of personnel, in particular PhD Studentships. The programme will aim to bring any tied students together in a coordinated way to maximise their learning and career development. There are currently existing RCUK Memorandum of Understanding co-funding mechanisms in place with the State of São Paulo Research Foundation (FAPESP) which could facilitate such activities, although it is not intended that the **SoS Minerals** programme works exclusively with FAPESP.

Scientific evidence on the environmental impact of strategic minerals in low carbon technologies will inform future UK, EU and international policy[15]. Links to existing FP7 networks and a proposed ERA-NET[16] gives access to international databases and opportunity for leveraging EU resources.

Opportunity for change

The **SoS Minerals** initiative offers a unique opportunity for UK research and industry communities to develop programmes of collaborative research at the interface of pure and applied sciences that can make a long-standing impact on the development of the new technologies and ways of processing the materials we will increasingly use as we tackle Global Change. At the same time **SoS Minerals** will shed light on the fundamental Earth processes that provide us with these opportunities.

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[14] Consultation with: Anglo American, Rio Tinto plc, Mineral Industry Research Organisation, Mining Association of the UK, Tertiary Mining, Wolf Minerals, AMEC, Environmental Sustainability KTN, http://www.miro.co.uk/

[15] e.g. UN International Seabed Authority; EU Marine Strategy Framework Directive; UNEP Action Plan for Human http:/www.unep.org/

[16] FP7 ProMine: pan-European GIS-database of known/predicted mineral resources. Proposed ERA-NET "ERAMIN" (BGS UK Lead) Network for Industrial Handling of Raw Materials for European industries, http://promine.gtk.fi/