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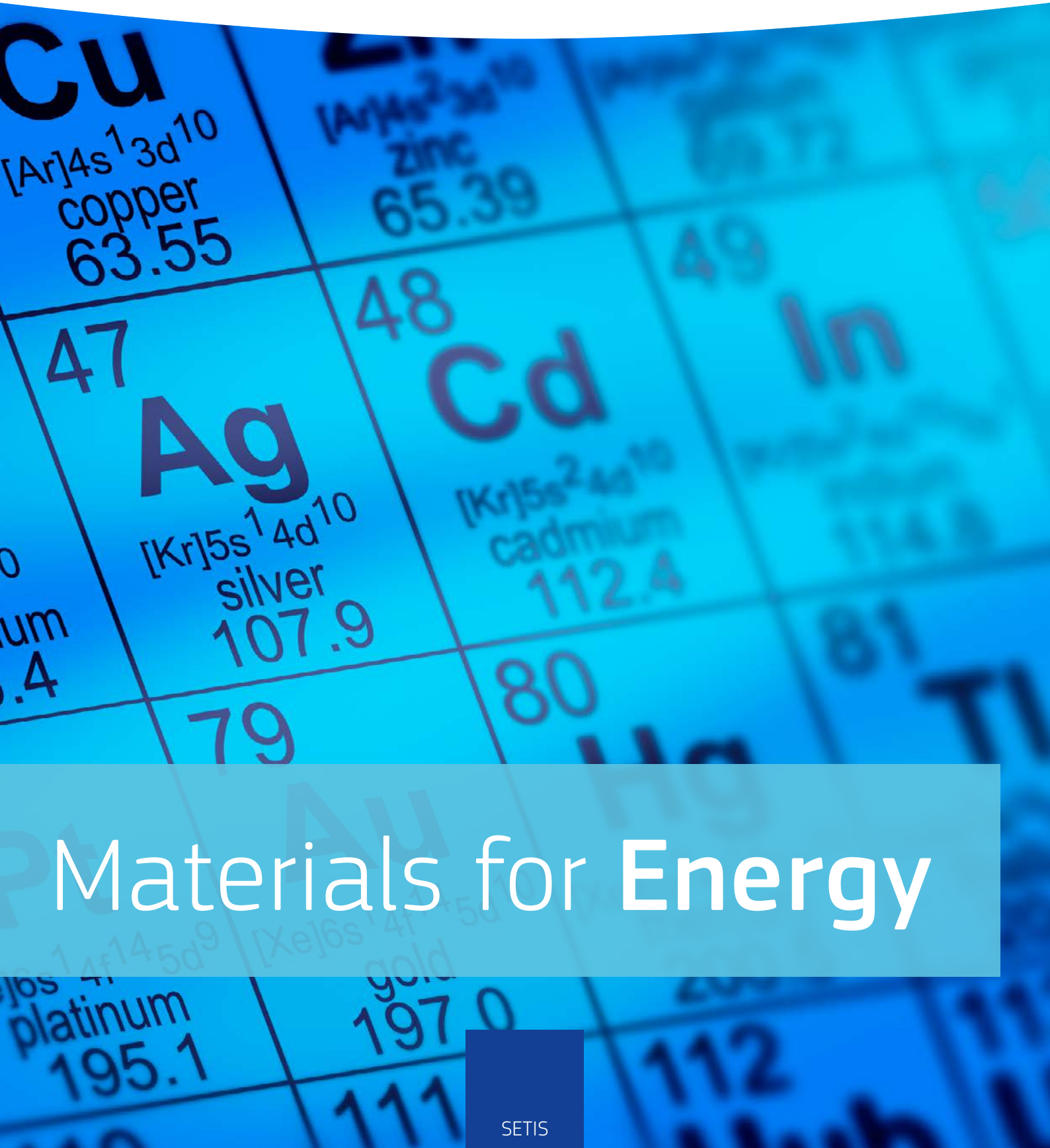

Materials for **Energy**

SETIS

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Editorial

By Fabrice Stassin
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No Advanced Materials - No Energy!

Among the many challenges faced by Europe, the new European Commission has clearly made Energy a top priority. Commission President Juncker wants a European Energy Union strongly rooted in low-carbon energy to support the SET-Plan targets of secure, affordable and sustainable energy.

The development and deployment of these low-carbon energy technologies needed to meet Europe's 2030 energy and climate goals is clearly enabled by advanced materials. Indeed, without continuous innovation in advanced materials, it would not be possible to increase the performance, reduce the cost and extend lifetime of low-carbon energy technologies.

Solar modules, wind turbine blades, batteries used to store energy all rely upon advanced materials developed and/or produced in Europe. The sector remains a strong provider of high-quality jobs for researchers, innovators, and operators while contributing to GDP from manufacturing. The future looks bright for advanced materials for low-carbon energy (the market could grow at about 10% per year from EUR 14 billion in 2015 to EUR 35 billion in 2030) but Europe's industrial leadership faces strong international competition.

Capacity for production of low-carbon energy through solar modules, wind turbines etc. is developing rapidly outside of Europe. Consequently, the manufacturing of advanced materials is also establishing close to end-markets and innovation activities may partially follow the trend. Safeguarding and reinforcing Europe's industrial leadership in strategic energy technologies and enabling competitiveness require the development and implementation of an appropriate industry and innovation policy framework.

Europe needs to focus on an ambitious innovation pillar to develop and manufacture better performing, less costly advanced materials. For instance, the efficiency of solar modules needs to increase, the weight of wind turbine components must be reduced and corrosion resistance improved, batteries need to demonstrate longer life cycles, and so on. Moreover low-carbon energy technologies often use critical metals whose potential scarcity must be addressed through advanced materials.

Reinforced public - private interactions between key industrial players, leading research organisations and the European Commission are of vital importance for Europe. These will lead to the launch of innovation programmes and the development of more European value chains serving green end-markets.

Only by partnering will we be able to accelerate the journey of advanced materials from the lab to the production line to the market for the benefit of Europe as a whole. Let's innovate!

EMIRI (Energy Materials Industrial Research Initiative) is the leading industry-driven association representing the interests of more than 60 organisations (industry, research, associations) active in the field of advanced materials for low-carbon energy. Our members represent at least EUR 4 billion of sales of advanced materials for low-carbon energy, they invest more than EUR 400 million annually in Research & Innovation for low-carbon energy and can mobilise several thousands of researchers and engineers. EMIRI aims to contribute to the industrial leadership of Europe-based developers, producers and key users of advanced materials for low-carbon energy technologies through the development of an appropriate industry and innovation policy framework based upon the SET-Plan. For more information, visit www.emiri.eu

JANUARY 2015

SET-Plan update

The European Strategic Energy Technology Plan (SET-Plan) aims to transform the way we produce and use energy in the EU with the goal of achieving EU leadership in the development of technological solutions capable of delivering 2020 and 2050 energy and climate targets.

Innovative materials are required for the manufacture of low-carbon energy technologies if Europe is to meet these energy and climate challenges in a cost-effective manner. The following is a chronological overview of some of the actions taken to promote advanced materials research across the EU, in addition to a more general look at recent actions in support of the SET-Plan.

Materials for Energy

- The European Commission has put in place two pieces of legislation aimed at improving the environmental management of waste electrical and electronic equipment (WEEE) and improving the collection, treatment and recycling of electronics: the **Directive on waste electrical and electronic equipment (WEEE Directive)** and the **Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive)**. The first WEEE Directive (2002/96/EC) entered into force in February 2003 and a revised version (2012/19/EU) came into effect in February 2014. The first RoHS Directive (2002/95/EC) came into effect in February 2003, with a recast (2011/65/EU) coming into effect at the start of 2013.
- The European Commission published **The raw materials initiative - meeting our critical needs for growth and jobs in Europe** (COM(2008) 699 final) as a first step towards helping the EU form a common approach in the international discussion on raw materials, building on an in-depth analysis carried out by the Commission in 2008, and on the results of a public consultation held during the same year.
- The Raw Materials Initiative was followed in 2009 by an Opinion of the European Economic and Social Committee on the **Non-energy mining industry in Europe** (2009/C 27/19), and in 2011 by an Opinions on **Processing and exploitation, for economic and environmental purposes, of industrial and mining waste deposits in the European Union** (CCMI/087) and by a Communication on **Tackling the challenges in commodity markets and on raw materials** (COM(2011) 25 final) in 2011.
- At the end of 2011, the Commission issued the Staff Working Paper **Materials Roadmap Enabling Low-Carbon Energy Technologies** (SEC(2011) 1609 final). This was followed in June 2013 by recommendations to the SET-Plan Steering Group and to the European Commission in the form of a paper on the implementation of the Materials Roadmap. In support of the Materials Roadmap, the Joint Research Centre, the European Commission's in-house science service, produced a series of scientific assessment reports covering various renewable energy technologies. These reports are available for download on the SETIS site.
- The European Energy Research Alliance organised a seminar to discuss a potential **Basic Science for Energy Joint Programme** in May 2010, after which a first document was produced and an awareness event was organised to widen interest in this JP initiative. Meetings were held in 2011 at which it was agreed that the areas where European research would be the most effective would be basic materials science, physical chemistry of processes, heat and mass transfer phenomena and dedicated powerful tools to characterise materials and energy devices. The JP was later renamed as the Advanced Materials and Processes for Energy Applications (AMPEA) joint programme.
- In 2011, the Institute for Energy and Transport at the Joint Research Centre published a study on **Critical Metals in Strategic Energy Technologies** to assess potential bottlenecks to the deployment of low-carbon energy technologies in the EU arising from shortages of certain metals. The study examined the use of metals in six low-carbon energy technologies, namely: nuclear fission, solar photovoltaics, wind, bioenergy, carbon capture and storage and the electricity grid.
- On November 29, 2011, the **Transatlantic Economic Council** (TEC) agreed to **a Raw Materials Work Plan**, which includes preparation of a joint inventory of mineral raw materials data and analysis maintained by both sides. As part of this effort, the two sides were instructed to consider the results of ongoing European Commission and United States government studies of

raw materials resource availability, trade flows, and criticality and of other supply and demand analyses, such as the 2010 European Commission Report by an ad-hoc expert group on critical raw materials and the U.S. Department of Energy Critical Materials Strategy.

- In 2011 the **EU, Japan and the US** launched a trilateral dialogue to promote cooperation in the field of critical materials. Within this context, a series of **Trilateral Conferences on Critical Materials** have been organised. The first conferences were organised in Washington (October 2011) and in Tokyo (March 2012) and the third such conference was held in Brussels in May 2013. The fourth Trilateral Conference on Critical Materials, which covered topics in the rare earth industry, source discovery, new materials research and deployment, and processing and recycling technologies, was held in Iowa, in the U.S. in September 2014.
- The **Energy Materials Industrial Research Initiative** was set up in 2012 to drive forward research and innovation in the advanced materials needed for low-carbon energy applications. By bringing together research, industry and trade organisations, and leveraging Europe's world-class capability in advanced materials, EMIRI aims to contribute to generating tangible growth in economic value and employment opportunities for Europe.
- **M-ERA.NET**, an EU-funded network to support and increase the coordination of European research programmes and related funding in materials science and engineering, was set up in 2012. M-ERA.NET aims to complement existing instruments and contribute to EU policies while supporting the exploitation of knowledge along the whole innovation chain, from basic research to applied research and innovation. The project aims to develop long-term cooperation between funding organisations across the EU. Cooperation with partners outside Europe is targeted at building a global network of public funding programmes.
- In line with recommendations from the Transatlantic Economic Council, an **EU-U.S. Expert Workshop on Mineral Raw Material Flows and Data** was held in Brussels on 12 - 13 September 2012. This workshop formed part of an ongoing effort in response to an EU initiative to set up a mechanism to collect raw materials data and analyse materials flow for EU countries. This was followed by another workshop in November 2013, hosted by the U.S. Geological Survey (USGS).
- The **European Innovation Partnership on Raw Materials** was set up in 2012 as a **stakeholder platform bringing together representatives from industry, public services, academia and NGOs.** Its mission is to provide high-level guidance to the European Commission, Members States and private actors on innovative approaches to challenges related to raw materials.
- In 2013, the JRC's Institute for Energy and Transport published a report entitled: **Critical Metals in the Path towards Decarbonisation of the EU Energy Sector**. This analysis of 17 energy technologies identified thirty-two materials as significant and, when market and geopolitical factors are taken into account, eight of them were given a high criticality rating, namely: the rare earth elements - dysprosium, europium, terbium, yttrium, praseodymium and neodymium; gallium and tellurium. Furthermore, an additional six were considered to have a medium-to-high risk and should be monitored closely: graphite, rhenium, hafnium, germanium, platinum and indium.
- The **Materials Information System** (MIS) was established in 2014 to provide relevant information on the materials used in SET-Plan technologies, including background information on the technology itself, the material's supply chain, which materials and how much material is used in each technology, descriptions of the materials themselves, both scientific and technical, as well as a library of relevant references, links and other literature.
- The European Commission's Ad Hoc Working Group on defining critical raw materials issued a **Report on Critical Raw materials for the EU** in May 2014. The purpose of this report is to revise and extend the work carried out in the 2010 report mentioned above, in order to produce an updated list of critical raw materials. This was followed, also in May, by a Communication '**On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative**' (COM(2014) 297 final). This Communication presents the new list of critical raw materials and provides an overview of the upcoming activities related to the Raw Materials Initiative, the European Innovation Partnership on Raw Materials and the part of Horizon 2020 that concerns raw materials.
- During the Euroscience Open Forum (ESOF) 2014 Conference, the European Commission's JRC organised a session entitled: "Raw materials supply: a bottleneck in the transition to a low carbon energy system". Distinguished speakers discussed the future demand and supply potential for raw materials used in energy technologies based on the expected technological development and market shares and addressed the potential risk to the EU decarbonisation and mitigation options.
- The European Commission is currently preparing a contractual public-private partnership (cPPP) on "Advanced materials enabling energy technologies". This new initiative is a contribution to the New Commission's Agenda for Jobs, Growth, Fairness and Democratic Change, in particular as an effort to create deeper and fairer internal market with a strengthened industrial base. The aim is to promote industrially-driven R&I actions aligned with the EU2020 objectives, the Integrated Energy Roadmap and the industrial needs throughout the advanced materials value chain in order to shorten the time to market for enabling energy technologies and to stimulate long-term R&I investments of the industry in the EU. This initiative will enable stronger and more complete value chains to drive competitiveness and to restore the EU's industrial leadership in strategic energy technologies.

General SET-Plan news

- The **7th Conference of the European Strategic Energy Technology Plan (SET-Plan)**, organized by the Italian National Agency for New Technologies (ENEA) under the auspices of the Italian Presidency of the Council of the EU, took place at the Auditorium Antonianum in Rome on 10-11 December 2014. The Conference provided a unique forum for experts, researchers, producers, stakeholders and representatives of national and EU institutions to have in-depth discussions on the future developments of the SET-Plan needed to respond to the energy challenges ahead.

Towards an Integrated Roadmap and Action Plan

Ahead of the SET-Plan Conference, the European Commission released the overview document "Towards an Integrated Roadmap: Research Innovation Challenges and Needs of the EU Energy System" prepared by the European Commission and reviewed and complemented with comments by the SET-Plan Steering Group, as well as consolidated inputs by stakeholders (Annex I: Parts I, II, III and IV), which address energy system integration challenges, as defined by the SET-Plan Steering Group. This input has been grouped under Themes for each Challenge identified by the SET-Plan Steering Group, to meet the three overarching energy policy objectives: security of supply, competitiveness and sustainability. The documents can be downloaded from the SETIS website.

- A **SET-Plan Steering Group meeting** was held in Brussels on 13 November. The main item for discussion at the meeting was the development of the SET-Plan Integrated Roadmap and Action Plan.
- The **Joint Research Centre** (JRC) has published a report on a **system-based approach to assessing the value of wind for society**. This report was based on a workshop held in Petten, the Netherlands earlier, the scope of which was to create and enhance a comprehensive list of social, environmental and economic elements which could or should be included in any analysis of the value of wind energy to society, depending on the purpose of each individual analysis. The workshop report is available for download on the SETIS website.
- The Joint Research Centre's Institute for Energy and Transport hosted a workshop in October on **power-to-hydrogen and hydrogen and compressed natural gas (HCNG)**, as part of an initiative launched by the European Association of Research and Technology Organisations (EARTO), the European Standards Organisations (ESO) CEN and CENELEC, together with the European Commission Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. This initiative was launched within the context of the European Forum on Science and Industry, to bring the scientific and standardisation communities closer together. The event was driven by the goal of providing European standardisation organisations with scientific input to ensure that European standards take into account economic competitiveness and societal needs such as environmental sustainability and safety and security concerns.
- The Joint Research Centre and the Ministry of Energy and Industry of Albania held a joint workshop on the **future role of energy storage in South Eastern Europe** in October 2014 in Tirana. The workshop is part of the Enlargement and Integration Action, in which the JRC is playing an important role by providing scientific and technological support through a number of activities. The participants actively discussed the technical, financial and regulatory challenges of the energy systems of the Western Balkans, and options for how these could be overcome. The presentations can be accessed on the workshop section of the SETIS website.
- The Joint Research Centre held a workshop in December 2014 on **addressing flexibility in energy system models**. The workshop aimed to gather experts from modelling teams dealing with the challenges facing the energy system of the future. These challenges include the effects of intermittent energy sources on the reliability and adequacy of the energy system, the impacts of rules governing the curtailment or storage of energy, and how much backup dispatchable capacity may be required to guarantee that energy demand is safely met. The workshop examined these problems from different perspectives, ranging from system-wide to detailed sectoral energy models, in order to share and compare modelling approaches and results, identifying gaps and potential solutions. Presentations from the workshop are available on the SETIS website.

SETIS TALKS TO:

Mattia Pellegrini

Head of Unit of Raw Materials, Metals, Minerals and Forest-based Industries within the European Commission's Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

On 26 May 2014, the Commission presented the first revised list of critical raw materials through a Communication on "the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative". The 2014 list now includes 13 of the 14 materials identified in the previous list of 2011, with only tantalum moving out of the list (due to a lower supply risk). Six new materials appeared on the list: borates, chromium, coking coal, magnesite, phosphate rock and silicon metal, bringing the number up to 20 raw materials which are now considered critical by the European Commission. The other 14 raw materials are: antimony, beryllium, cobalt, fluorspar, gallium, germanium, indium, magnesium, natural graphite, niobium, platinum group metals, heavy rare earths, light rare earths and tungsten.

Mr Pellegrini, you are Head of Unit of Raw Materials, Metals, Minerals and Forest-based Industries within the European Commission's Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. What is your mission?

M.P.: "Within the European Commission, DG for Internal Market, Industry, Entrepreneurship and SMEs, I am in charge of managing the implementation the "Raw Materials Initiative" (RMI), which is the main instrument at European level dealing with Raw Materials policy. Its aim is to manage raw materials issues at the EU level. This Raw Materials Initiative has three pillars, the first of which is fair and sustainable supply of raw materials from global markets. The second pillar is fostering sustainable supply within the EU. The European Commission has an important role in bringing the Member States together and fostering the exchange of best practice. Finally, the third pillar is about boosting resource efficiency and promoting recycling. In order to reinforce the work carried out under the RMI, the Commission has also set up an expert group — the Raw Materials Supply Group (RMSG). It has representatives from Member States, other EEA countries and candidate countries as well as from organisations representing stakeholder interests from industry, academia, and others. It advises the Commission and oversees the Initiative's implementation."

Raw materials have been high on the political agenda for a number of years, why is this?

M.P.: "While the importance of energy materials such as oil and gas has often been highlighted, historically the indispensable role of metals and minerals has had a lower profile. During the last decade we have observed a major increase in demand for metals and minerals. Hence it became clear to policy-makers at European and national level that the EU is highly dependent on the production and, of course, also the importation of raw materials. These raw materials are fundamental and a key driver to ensure sustainable growth and competitiveness. They are also one of the keys towards a smooth transition to a low-carbon economy. Most of the wind turbines use magnets which are made from critical raw materials, a classical example of which are the rare earths. This also partially explains why the EU, together with its partners including Japan and the US, has been active in challenging recent export restrictions on raw materials such as rare earths. The EU and its partners have been successful and won both of these cases."

How dependent are we on imports of raw materials from outside the EU?

M.P.: "It really depends on the type of raw materials. The report on Critical Raw Materials for the EU which DG for Internal Market, Industry, Entrepreneurship and SMEs published in May this year confirmed that for the production of construction minerals, for instance, the EU is self-sufficient. The EU also has a large production of industrial minerals supplying a very wide range of industries. For some minerals, such as magnesite, fluorspar, bentonite, kaolin and potash, Europe is an important global producer. However, one should be aware that the EU is also a net importer for many of these industrial minerals.

The report also identified that around 90% of the global supply of 54 raw materials assessed originated from extra-EU sources. This figure included most of the base, speciality and precious metals. It is not a surprise that China is the major supplier for these materials. This is clearly the case, among others, for rare earth elements which are among the most critical raw materials. However, many other countries are also important suppliers of specific materials: South Africa supplies platinum group metals and Brazil - niobium. The EU primary supply across all candidate materials is estimated at around 9%. Europe produces for instance copper, lead, silver and zinc but the production is not high enough to supply domestic demand. In the case of critical raw materials, supply from EU sources is even more limited. At the Commission we strongly believe that the potential for the production of (critical) raw materials is largely untapped."

Why does the European Commission publish a list of critical raw materials, what is its purpose?

M.P.: “The list of critical raw materials is a key instrument for policy making and serves as a tool to secure supply of these materials. Through the list, the Commission also intends to focus on the European production of critical raw materials. We want to facilitate the launching of new mining and recycling activities. It is part of our contribution to the implementation of the EU industrial policy and to ensure that European industrial competitiveness is strengthened. This should increase the overall competitiveness of the EU economy, in line with the Commission´s aspiration of raising industry's contribution to GDP to as much as 20% by 2020. However, it is worth emphasising that all raw materials, even if not classified as critical, are important for the European economy. A given raw material and its availability to the European economy should therefore not be neglected just because it is not classed as critical.”

What has been the concrete impact of the list of critical raw materials?

M.P.: “The list is also being used to help prioritise needs and actions. It serves as a supporting element when negotiating trade agreements, challenging trade distortion measures or promoting research and innovation. For instance, under Horizon 2020 several call for proposals contain a reference to “critical raw materials” which implies that applicants are invited to focus – where possible – on those raw materials that are deemed critical. Furthermore, the list is being used as an instrument to raise awareness among policymakers and all relevant stakeholders. Member States are more and more designing national raw materials policies and some of them have been developing their own list of critical raw materials, for which the European list serves as an example. Another example are the universities, we have dedicated budgets to finance PhD students for research on rare earths for instance, which are among the most critical raw materials. We have also noticed that several raw materials commitments under the European Innovation Partnership tackle specific problems related to to the supply of these critical raw materials. For those interested, I am glad to announce that there will be a new Call for Commitments in 2015. All stakeholders are invited to participate.”

The study on critical raw materials also contains an annex on sector-specific discussions on critical raw materials which include defence, energy technologies and ICT. Why is that?

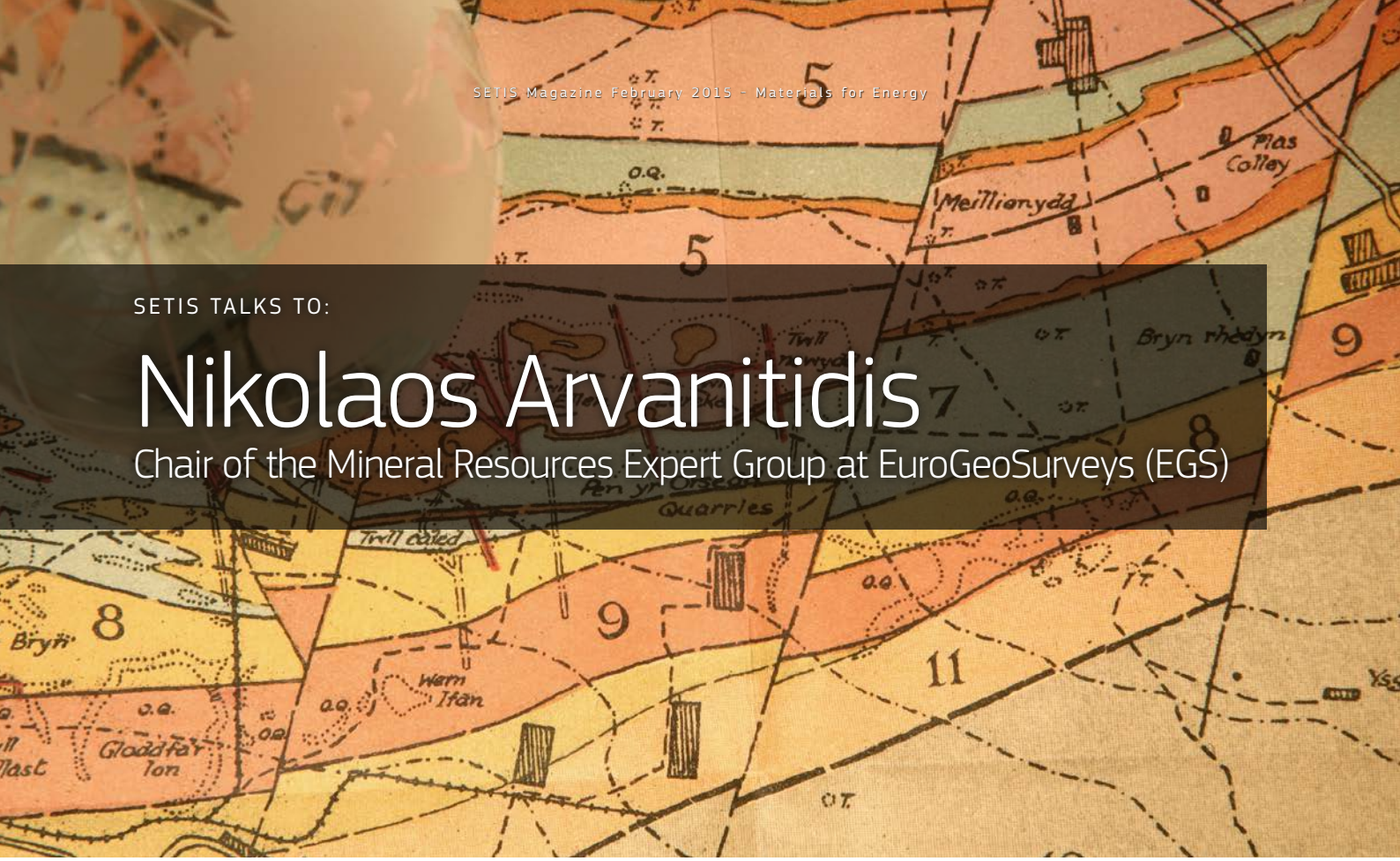
M.P.: “For the first time the study on Critical Raw Materials also covered some sector specific information. This was the case for ICT, energy technologies but also defence. For these sectors, the raw materials that are deemed “critical” can sometimes vary. The Joint Research Centre has done excellent work in identifying raw materials that are critical for the EU energy sector. We have therefore requested the JRC to do the same for the defence sector.”

Will there be a follow-up of the list of critical raw materials?

M.P.: “Yes, the European Commission has a political commitment towards the Member States and the European Parliament to come up with a revision of the list of critical raw materials at least every three years. We therefore expect the next list to be ready by 2017. Although we strive at ensuring maximum comparability with the previous list of critical raw materials, we strongly envisage making an assessment of the currently used methodology. The Joint Research Centre (JRC) would be in charge of this exercise. Concretely the JRC would be asked to provide DG for Internal Market, Industry, Entrepreneurship and SMEs with technical assistance, analysis, appropriate data and support for the assessment of the methodology that has been applied for the publication of the list of critical raw materials for the EU in 2011 and 2014. Following this assessment, a refined – and where appropriate – revised methodology could be envisaged for the next revision of the list of critical raw materials. The work would also be closely followed by our specific expert group the “Ad hoc Working Group on Defining Critical Raw Materials for the EU”.”

Mattia Pellegrini

is currently Head of Unit for Raw Materials, Metals, Minerals and Forest-based Industries at the European Commission's Directorate General for Internal Market, Industry, Entrepreneurship and SMEs. Previously, he worked as Head of Cabinet of Commissioner Nelli Feroci and as a Member of the Cabinet of the Vice President of the European Commission, in charge of Enterprise and Industry. Mr. Pellegrini has a Master's Degree in European Legal Studies obtained at the College of Europe, Bruges, and a postgraduate diploma in EC Law obtained at L.U.I.S.S. “Guido Carli”, University of Rome.



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SETIS TALKS TO:

Nikolaos Arvanitidis

Chair of the Mineral Resources Expert Group at EuroGeoSurveys (EGS)

What is the role of EuroGeoSurveys (EGS) and how does its work contribute to the security of Europe's supply of critical materials?

N.A.: "The role of EGS is to provide public Earth science knowledge to support the EU's competitiveness, social well-being, environmental management, and international commitments. Through its Mineral Resources Expert Group, EGS has the capacity and capability to deliver the best available mineral expertise and information based on the knowledge base of its members' geological surveys, for policy, industry, communication and education purposes at a European level. EGS aims to become the leading partner within a European mineral information network, or similar cooperative undertaking, which will provide innovative tools and expertise to support sustainable minerals supply for Europe. Mineral information provided by EGS is based on globally comparable standards of excellence for research and development, and there are processes for these standards to be maintained. Of course, to make this happen many of EGS mineral activities and tasks are carried out collaboratively with other organizations that have mineral information and expertise, and with consumers of that information and other potential stakeholders.

Within this context, the EGS and Geological Surveys of Europe are currently carrying out the EU-funded Minerals4EU project, which should create the main European information network structure on minerals (including critical ones) to provide tools and expertise to enhance resource efficiency and the security of minerals supply, and support sustainable minerals development for Europe. A Knowledge Base Platform is being developed to enable a dynamic value chain, delivering added-value intelligence and foresight information, and prompting the development of a permanent structure to achieve and facilitate sustainable services. The exact nature of the data concerning primary and secondary mineral and metal resources, on land and offshore, and supply and demand data, will be defined by the Minerals4EU project and the potential network partners, enabling the delivery of concrete products such as a web portal, the European Minerals Yearbook and a foresight study.

A four-year (2009–2013), EU co-funded project, ProMine has created and provided a well-documented knowledge base of Europe's non-energy raw material resource potential. The database demonstrates that Europe hosts a large number of mineral deposits ranging from precious metals (gold, silver, platinum group elements), base metals (aluminium, copper, lead, zinc, tin), iron and metals used to make steel (cobalt, chromium, manganese, nickel, vanadium, tungsten), high tech and rare metals (bismuth, germanium, gallium, mercury, lithium, rare earth elements, antimony, tantalum, titanium, zirconium), minerals for chemical use (e.g. barite and fluorite) to fertilizer minerals (e.g. phosphate), building materials and several other industrial rocks and minerals.

EURARE is a project funded by the European Commission for the 'Development of a sustainable exploitation scheme for Europe's Rare Earth ore deposits'. The rare earth elements (REE) are vital components of many modern technologies, including electric and conventional cars, computers and smartphones, renewable energy infrastructure, and phosphor lighting. The main goal of the EURARE

project is to set the basis for the development of a European REE industry that will safeguard the uninterrupted supply of REE raw materials and products crucial for the industrial sectors of the EU economy, such as automotive, electronics, machinery and chemicals, in a sustainable, economically viable and environmentally friendly way. The Geological Surveys involved in the project discovered that Europe has currently no mine supply of REE, but it does have a number of areas of suitable geology with REE resources. These include alkaline igneous rocks such as those found in the Gardar Province of south west Greenland (Kvanefjeld and Kringlerne exploration projects) and within the Fennoscandian Shield (including the carbonatites of Fen in Norway and Sokli in Finland and the Norra Kärr syenite in Sweden). They also include secondary placer deposits such as those in Greece and Serbia. Based on information received from ongoing advanced exploration projects there is potential for more than 6 Bt of ore resources, more than 38 Mt TREO (total rare earth oxides) and more than 10 Mt HREO (heavy rare earth oxides).

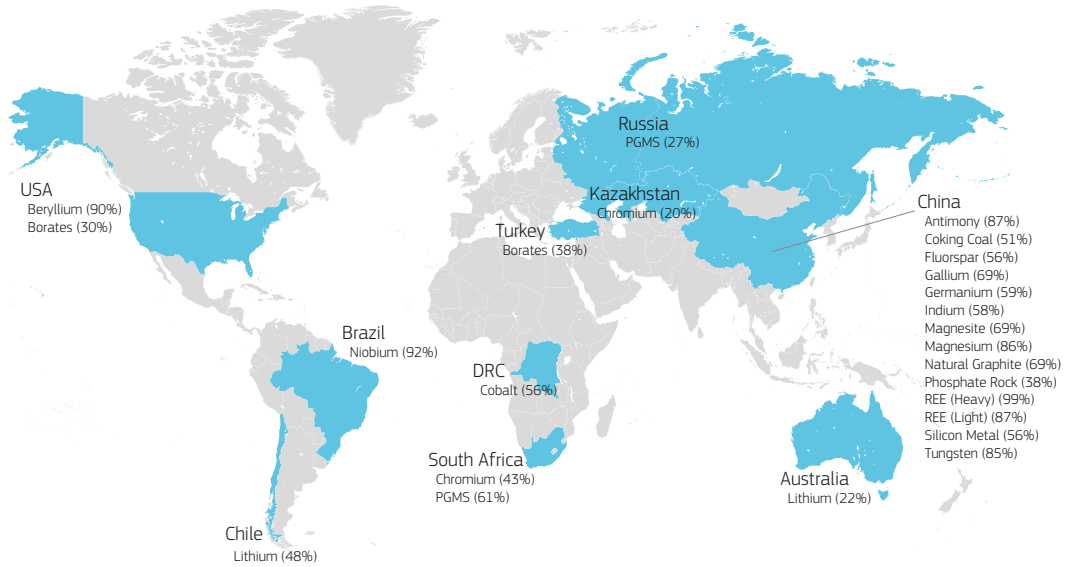
The main message from the Geological Surveys' point of view is that the problem is not the geology and metallogeny of Europe but the lack of critical raw materials-focussed exploration. Europe needs to apply more efficient exploration including dedicated ore genetic studies to better understand the critical minerals systems. ”

Where are these critical materials extracted and refined, where and how large are the main markets, and how tough is the competition for these resources?

N.A.: “ China is the major supplier when these materials are considered, however many other countries are important suppliers of specific materials; for instance, Russia and South Africa for platinum group metals. By contrast, supply of critical raw materials is more limited, with less than 3% of critical raw material supply arising from within the EU. The major producers of the twenty-one EU critical raw materials are shown below (Fig 1), with China clearly being the most influential in terms of global supply.[1] Several other countries have dominant supplies of specific raw materials, such as the USA (beryllium) and Brazil (niobium). Supply of other materials, for example the platinum group metals (PGM), lithium and borates, is more diverse but is still concentrated.

As a matter of fact, total supply across all twenty critical raw materials can be estimated at under 3%, with over half having no or very limited production within the EU. The critical raw materials with the highest production in the EU are gallium (12%), magnesite (12%), silicon metal (8%) and germanium (6%). The demand for all the critical raw materials is predicted to grow, with niobium, gallium and heavy rare earth elements forecast to have the strongest rates of demand growth, exceeding 8% per year for the rest of the decade.

China is the major miner and refiner of critical raw materials (CRM). Most critical minerals and metals are extracted and refined there. In addition to making dynamic supply markets they are also competing with the USA, Japan and the EU when it comes to the productivity of downstream manufacturing industries. For example China controls one third of world REE reserves and, along with other Asian miners, 94% of global REE production. In 2010, 97% of REE mining and concentration, 97% of REE separation of ores into oxides and almost 100% of refining of REE oxides to metal took place in China. Furthermore, 75-80 % of REE magnet alloy powder production occurred in China, while the remainder took place in Japan. In terms of the final stage of magnet manufacturing 75-



Source: Oakdene Hollins and Fraunhofer ISI, Study on Critical Raw Materials at EU Level

80% took place in China, 17-25% in Japan and only 3-5% took place in Europe.

China and other BRIC countries are also major consumers of CRM. Europe is not a significant consumer of REEs, though REEs are used in key European industries. European consumption has remained stable since 2011, averaging around 2 400 t REO (rare earth oxides). Overall the global CRM market is not managing to stabilize, with unforeseen changes in Chinese trade policy on one hand and the uncertain situation with resource exploitation in Greenland and elsewhere in Europe, on the other. ”

What are the main materials relevant to the renewable energy sector for which supply bottlenecks might occur and what consequences might these bottlenecks have for the renewable energy technologies in question?

N.A.: “ Improving environmental performance is something that is closely linked to raw materials, both at present and in the future. Exhaust emissions from internal combustion engines are managed through catalytic converters containing platinum group metals; for which no other option is viable at present. Low-carbon technologies also require that the correct resources are available. Many wind turbine designs use magnets containing rare earth elements, and solar panels rely on metals such as silicon, tellurium and indium amongst others. Similar cases are seen for electric vehicles and energy efficient lighting. Massive growth in the use of electric and hybrid vehicles will be accompanied by equally high levels of demand for the rare earth elements needed to manufacture their batteries and propulsion units.

There is a range of socio-economic factors involved here, such as concern about the environment, the cost of energy, social license to operate and conflict. In a changing world, these factors are likely to become increasingly significant. It seems that, to an increasing extent, extraction of mineral resources must compete with other interests. Documented spatial databases of reserves/deposit areas are therefore of importance for influencing future land use. ”

What steps can the EU take to guarantee supplies of these materials?

N.A.: “ In addition to concerns about dependence on extra-EU supplies, the production of many materials is reliant on just a few countries. This concentration of supply is also cause for concern as countries dominate supply of individual or several materials: Brazil (niobium), USA (beryllium), South Africa (platinum) and China (rare earth elements, antimony, magnesium, and tungsten). In fact, twenty countries are the largest suppliers of critical raw materials, accounting for 90% of supply. All major suppliers of the individual critical raw materials fall within this group of twenty countries. At the same time, all are predicted to experience demand growth, with lithium, niobium, gallium and heavy rare earth element forecast to have the strongest rates of demand growth, exceeding 8% per year for the rest of the decade.

Analysis has highlighted the different stages on the supply chain where countries are placed and, consequently, the different approaches being taken. For example Japan is focusing heavily on substitution, China - on processing and metallurgy, South Korea - on recycling, Australia - on sustainable mining and Canada - on exploration. Funding for some of these programmes can often be vast, for example South Korea is investing $300m (EUR 244m - Dec. 2014) over 10 years into research into forty technologies covering refining, smelting, processing, recycling and substitution. Other strategies have also been adopted. Russia is also known to have an active programme for materials stockpiles and export restrictions, China has tightened the export quotas for rare earth elements, ostensibly to secure internal supply, and the US has long had a stockpile for strategic defence materials.

There is a need to focus on exploration and make it more effective. Resources need to be found before any extraction, processing and refining can be discussed. Discovery of new resources needs enhanced information on surface and subsurface geology, new concepts for natural resource potential, particularly in underexplored areas about which there is limited geological knowledge, and projects that span the geosciences and are truly multidisciplinary. The question “Where are undiscovered mineral resources likely to exist, and how much undiscovered mineral resource may be present?” needs to be answered. All of the processes involved in the formation of a deposit, a good understanding of why mineral deposits occur where they do, ore exploration models and resource assessment studies, are significant steps that need to be taken. Irrespective of the exploration level, a better understanding of the geology and delivery of high-quality maps may lead to new or little-known types of ore deposits and ore-forming systems. In addition, future exploration will likely need to focus increasingly on deeply buried deposits.

Europe’s mineral potential is under-explored, both with regard to the subsurface (particularly deeper than 150 meters) and the seabed in the EU Member States’ exclusive economic zones. Major opportunities for access to raw materials exist within the EU today, especially for mining at greater depths or in small deposits. The ocean bed could also contain valuable raw materials, such as copper, zinc, gold, silver and rare earth metals, leading to growing world-wide competition for marine mineral deposits. A framework of stable economic and technological conditions makes sustainable and resource efficient exploitation possible in Europe.

There is a challenge to better understand ore genesis and direct exploration at deeper, unexploited levels of the bedrock. This may be possible by developing and applying innovative exploration technologies (3D/4D) to locate deep-seated deposits, and to define the critical raw materials reserves (including secondary resources) of the EU. ”

As emerging economies develop their renewable energy industries and other high-tech sectors, the pattern of demand for materials is likely to change. What are the likely consequences of this for the European Union?

N.A.: “ Non-energy minerals underpin our modern economy. They are essential for manufacturing and renewable 'green' energy supply. Despite the recent financial downturn across the globe, demand for raw materials, such as non-energy minerals, is set to increase as attempts are made to boost economies and push the growth of manufactured goods. The supply of minerals will, therefore, be necessary into the future. Most of the environmental technologies and applications (e.g. wind turbines, photovoltaic cells, electric and hybrid vehicles) allowing energy production from renewable resources will use so-called high-tech metals (e.g. REE, PGM, niobium, lithium, cobalt, indium, vanadium, tellurium, selenium) that are derived or refined from minerals for which Europe is strongly import-dependent. We need to calculate the volumes of critical and potentially strategic metals (e.g. cobalt, niobium, vanadium, antimony, platinum group elements and REE) and minerals that are currently not extracted in Europe in order to understand how high-tech elements are mobilised, where they occur and why some are associated with specific major industrial metals.

The UN forecasts that the global population will be 10.9 billion by 2050, an increase of 50% on current levels. Looking ahead to 2050, China will have more than 200 cities with more than 1 million inhabitants. Population growth and economic development will continue to drive mineral resource use on an upward trajectory. Global production of platinum group elements has increased by 113% between 1980 and 2008.

The high import-dependence of strategic and critical minerals has serious implications for the sustainability of EU manufacturing. This problem can only be resolved by more intense and advanced exploration for new mineral deposits on land and offshore. Incidentally, mineral resources on the seafloor are the focus of growing European interest with respect also to the exploration potential of rare earth elements, cobalt, selenium, tellurium and other high-tech metals. ”

Substitution and recycling are two approaches to dealing with potential supply constraints. Is enough being done at a policy level to support research into substitute materials and to promote recycling of critical materials?

N.A.: “ A coherent resource-efficient product policy framework contributes to the sustainable supply of raw materials, through resource efficiency and recycling, to reduce the EU's dependency on imports of many of mineral resources, including critical metals. To recycle and re-use waste materials and by-products from all mineral value chain activities, in order to increase the supply of valuable secondary resources, is an ongoing goal. Many critical minerals and metals may be collected through recycling of mining related waste materials. However, even with the important contribution from recycling, to secure resource efficient supply it will still be necessary to extract primary mineral deposits, focusing on the application of new technologies for deep exploration and mining, turning low- grade ores to exploitable resources and reducing the generation of mining wastes and large tailings by converting them to exploitable resources, thereby resolving environmental footprint issues. The major bottleneck in recycling is regulations and politics. In any case, as mentioned, recycling will increase in importance but is not a stand-alone solution for the EU.

When it comes to substitution, priority shall be given to critical raw materials. Finding substitutes should be linked to the risk associated with their production as well as the substitutes themselves. Attention should also be placed on by-products. On the other hand substitutes may also contribute to the development of nano-products. ”

A leading producer of rare earth metals - China - has introduced export restrictions on some raw materials, increasing the price of these materials for EU industry. Are international trade rules sufficient to address this issue, or are there other measures that the EU can take to create a level playing field?

N.A.: “ Some information about the global and European situation on REE mineral resources has already been delivered in the previous answers. There is currently exploration potential and high prospective interest in primary deposits in Greenland and the Nordic countries, and secondary deposits in mainly NW France, Greece and the west Balkans.

However my personal opinion is that optimism and realism rarely go hand in hand, and this is clearly the case with REE in Europe. By now, it is well known that political reforms, economic re-orientation and high industrial growth rates in China have led to a tremendous upward spiral in mineral consumption, in this case accompanied by a shift of emphasis to high-tech and base metals, and industrial minerals for steel manufacturing and building. In short, China

alone is changing global mineral production and demand figures. The country's national or, to be more correct, government mineral policy has become the only exploitation strategy implemented by all state-owned mining companies. The country's growing needs for mineral resources were to be met at all costs, with environmental issues taking a back seat. However, the country was not self-sufficient in essential mineral raw materials and that resulted in the increased interest of Chinese miners in international resources and markets. For example, China currently controls the up- and downstream REE supply chain industry. It is the only functioning economy in the world with respect to REE exploration, mining, processing, refining and metal production. Nevertheless, there is currently a strong Chinese interest in global investments as they need additional sources of REE.

Following these developments, the EU had to address these new challenges and ensure that the appropriate technologies, processes and products were in place, along with adequate policies to implement and stimulate the required changes. Europe is not self-sufficient in the extraction of essential mineral raw materials with industrial REE supply almost 95% import-dependant on average. However there is serious concern about whether things are going in the right direction to strengthen Europe's position in the REE supply chain. At a first glance, the options and expectations look neither optimistic nor realistic. The EU has delivered initiatives, strategies, and criticality reports on mineral raw materials, has mobilized almost all its experts and put a lot of resources into its efforts. But to date there have only been a few advanced exploration projects in Europe and Greenland, with unclear schedules for mining, extraction, processing and metallurgy, although REE mineral resources from European sources (e.g. the EURARE project, the ERECON network) seem to be there. In contrast to China, the development of REE exploitation in Europe is progressing slowly, with the absolute need for consensus among the Member States not being the only problem.

Most of the European REE projects are currently in the hands of junior prospecting or mining companies that are probably unable to proceed downstream in the supply chain through all the stages of the exploitation process. They naturally do things based on their own corporate strategy and not based on the citations and recommendations of any EU strategy. As a result, should they manage to proceed with mining it is uncertain whether they will reach metallurgy production or be satisfied by producing ore concentrates only.

It seems to be the case that Greenland, although they have had several dialogues with the EU, would really like to see things move faster and this might bring them to even closer and more concrete agreements with the Chinese. For the EU industrial economy it is important to have metallurgy in Europe. This is where the technology and the added value are. Of course for China, with the entire exploitation and supply chain in place, the country could become more interested in continuing to be the main controller and key actor by simply importing REE mineral raw materials and processed ores from other parts of the world, including Europe and Greenland. Is there any way for the EU to stop or even control this trend in a more efficient and determined way? Nobody can provide a concrete answer today. Europe needs to ensure that things are implemented and operated more quickly and to advance the entire supply value chain. REE and other critical raw materials should also be considered strategic, as this would make governments more interested and active and ensure a focus on more operational involvement in the exploitation and production process. ”

1. http://europa.eu/rapid/press-release_MEMO-14-377_en.htm

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Electric vehicles and critical metals

Electric vehicles, like many low carbon technologies, use a number of different exotic metals in their design. Many of these metals are considered 'critical' in that they are necessary to the development of the electric vehicle market, and yet the availability of sufficient quantities of these metals for future market demands has been questioned.

A number of different types of vehicle design utilise electricity for drive, including hybrids, plug-in hybrids, fuel cell vehicles and battery electric vehicles. Common to these designs are electric motors and batteries, both of which contain critical metals. While a number of competing battery technologies exist, lithium-based battery chemistries are the current batteries of choice for electric vehicle manufacturers and lithium has been raised as a critical metal. Many electric motors use high-powered magnets in their design. These magnets contain neodymium and dysprosium, which are both rare earth elements often cited as critical metals.

Opinion is divided on whether the availability of these metals could become a 'showstopper' for the electric vehicle market. While this topic is beset by a number of uncertainties a greater exposition of the important issues for electric vehicle materials can shed some light on these emerging concerns.

First it is important to understand the nature of future demand for electric vehicle materials. A number of scenarios project significant increases in future electric vehicle sales. For example, the International Energy Agency estimates that by 2050 annual sales of battery electric vehicles will reach ~50 million vehicles a year[1]. These scenarios, and the prospects for future electric vehicle sales, are dependent on climate policies, and the changing nature of our future aspiration to decarbonise is an uncertainty that could significantly affect the electric vehicle market. Nevertheless, projected electric vehicle market growth suggests that future demand for lithium and neodymium could become many times current lithium or neodymium supply[2].

The electric vehicle market must also compete for access to critical metals with several other uses. Lithium batteries are increasingly used in consumer electronics, and lithium is also used as an additive to ceramics and glass. In the US these end uses account for 56% of lithium consumption[3]. Magnets containing neodymium can be found in many consumer products including computer hard drives and audio speakers and headphones. Other metal alloys, magnet uses and use in catalysts represented ~60% of neodymium demand in 2010[4].

Opportunities exist to reduce the demand for critical metals in electric drive vehicles. Different vehicle designs have different metal requirements and favouring vehicle designs that use less critical metals could mitigate availability constraints for certain metals. For example, battery electric vehicles are likely to have the highest demand for lithium, as they require larger batteries, while fuel cell vehicles may require significantly smaller batteries and therefore less lithium[5]. However, hydrogen fuel cells require platinum, and switching between vehicles may just be substituting one critical metal for another. Alternatively, substitution within vehicle components may provide similar demand-reducing effects. While permanent magnet motors are widely used in electric vehicle designs, induction motor designs also exist, and do not require neodymium magnets.

When looking at critical metal supply a great deal is expected of producers if they are to keep up with the significant increases expected in demand. Lithium is recovered from mineral deposits and brines found in salt flats. The U.S. Geological Survey (USGS) cites a significant and growing quantity of economically-recoverable reserves, and also a large quantity of resources potentially economic in the future. A range of other reserve and resource estimates indicate that known quantities of lithium appear to be increasing over time[2]. In contrast neodymium, like many other critical metals, is recovered with a number of other metals, and the economics of its extraction are therefore dependant on these other metals. As a result, producers may not respond to price signals in the way expected in other commodities markets, and a high neodymium price might not be sufficient to encourage increased rare earth metals production[4]. However, producers can favour rare earth ore that has particularly high concentrations of certain high demand metals to help balance with the priorities of the end use markets.

Geopolitical issues also impact on availability of these metals. For example, China produced over 90% of global rare earth metal in 2013[6], with some suggestion that the global rare earth market is therefore overexposed to Chinese export policy. However, global reserve endowment is much more balanced, with less than 40% of global reserves thought to exist in China. Rare earth extraction projects in regions outside China will begin to impact on the geographical distribution of rare earth metals production[6].

Metal recycling is another way to reduce the burden on mining production. However, the contribution that electric vehicle recycling can make will take some time to realise, as the metal components may be tied up in electric vehicles for many years. Once these vehicles reach the end of their usable lives their metals will become recoverable, but recovery rates will be less than 100%, reducing the impact that recycling can make to annual production[5].

Historical production data indicates that production of many critical metals, including lithium and neodymium, is on an increasing trajectory. However, how long into the future these trajectories can be maintained and whether growth will be sufficient for future electric vehicle demand is uncertain. Whether or not the debate over critical metals in electric vehicles is resolvable, there does appear to be a number of mitigating factors that will aid electric vehicle manufacturers in the face of constrained metal supply. On the demand side, several substitution opportunities give manufacturers a way to avoid constrained metal supply chains and the high metal prices that will follow. For supply, the rate of production growth and the growth in estimated reserves and resources holds some optimism for meeting future demand. In addition, recycling can play a part in meeting this future demand.

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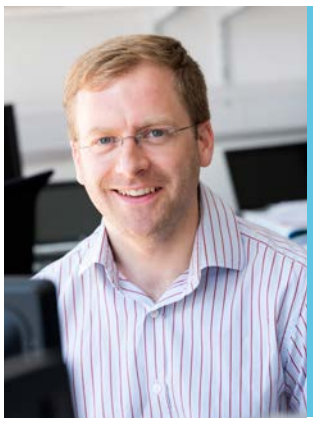

Jamie Speirs

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SETIS FEATURE ARTICLE

LED - lighting the way to an energy-efficient future

Light-emitting diodes, commonly called LEDs, are a technology that uses semiconductors and electroluminescence to create light. LED lighting can be more efficient, durable, versatile and longer lasting than traditional incandescent light bulbs or compact fluorescent lamps (CFL). As a result, LEDs have become the standard lighting technology for mobile phones, flat-screen televisions, tablets and computer monitors, and growth in global demand for LEDs has largely been driven by the expanding market for these consumer goods. The other main application of LED technology is in street and space lighting - but the timing and penetration of LED lighting versus phosphor (fluorescent) lighting will play a key role here. Forecasts show LED penetration reaching 30% of the total European lighting market by 2015, 46% by 2016, and 72% for 2020 (JRC 2013 / McKinsey, 2012).

This growth in demand for LEDs has gone hand-in-hand with growth in demand for the critical raw materials used in their manufacture. White light LEDs contain a range of different metals, such as nickel, gallium, arsenic, indium, antimony, cerium, europium and yttrium (JRC 2013). Lutetium and gold are also used in LED production. Gallium arsenide (GaAs) has historically been the most widely used gallium compound semiconductor in LEDs, largely thanks to the fact that it is a faster and more efficient substrate material than silicon and is able to operate over a wider range of temperatures. However, the use of gallium nitride (GaN) semiconductors is expanding. GaN power semiconductors can operate at higher temperatures, power levels, voltages and frequencies than gallium arsenide and silicon and GaN semiconductors are used in LEDs for backlighting of liquid crystal display (LCD) flat panel displays in computers, TVs and mobile telephones, and in signage.[1]

In 2013 the Joint Research Centre - the European Commission's in-house science service - conducted a study on Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector, which aimed to identify the metals for which bottlenecks could form in the supply chain of various low-carbon energy technologies. The list of eight metals that were given a high criticality rating and therefore classified as 'critical' in the report includes two of the LED

components mentioned above - gallium and, to a lesser extent, yttrium. Demand for critical raw materials is predicted to grow generally but, largely thanks to their use in two emerging energy-related applications - LED lighting and solar photovoltaic - the average growth in demand to 2020 for gallium and for heavy rare earths such as yttrium is forecast to be particularly strong, at greater than 8% per year for the rest of the decade.[2] Growth in the other main market for gallium – semiconductors - is relatively more modest at around 6% per year (Indium Corporation, 2011). These forecasts clearly indicate that the demand growth for gallium will be very high and that, consequently, there is a risk of market deficits for these materials.[3]

According to a report from Roskill Information Services, Chinese capacity for primary gallium production has increased and accounted for 80% of the global total in 2013. As a by-product of aluminium refining, gallium is highly dependent on one of the most energy intensive metal refining industries. Consequently, it is a resource that the Chinese government has put limitations on in the past.[4] Despite an increase in global production capacity, the U.S Geological Survey estimates world production of primary gallium at 280 metric tons in 2013, down 27% from 383 tons in 2012.[5] China, Germany, Kazakhstan, and Ukraine were the leading producers; countries with lesser output were Hungary, Japan, the Republic of Korea, and Russia. Refined gallium production in 2013 was estimated at 200 tons, about 30% less than primary production. China, Japan, the United Kingdom and the United States were the principal producers of refined gallium. Recycling, particularly in Japan, is also an important element of supply.

In light of China's monopoly of the market for primary gallium - Europe is faced with a number of options. Although Europe already has a degree of self-sufficiency for gallium and tellurium, a number of opportunities may exist to further boost supply of these materials. One strategy is to adapt technologies and production processes with a view to reducing the amount of critical materials required. Another is to find substitute materials that perform as well or nearly as well at a comparable cost. In this regard, quantum dots are a promising technology for lighting applications. The first commercial lighting applications of quantum dots used them as a coating on blue LEDs to help create a warmer white light - these are known as quantum dot LEDs (QD-LED). Organic light emitting diodes (OLEDs) also have the potential to become a viable rare earth-free alternative to other low-energy lighting technologies such as LEDs and fluorescents. A third option to shore up the European market is to find new or enhanced recycling technologies to increase available supplies.[6]

One project that aims to do just this is CycLED,[7] which is being financed under the European Commission's Seventh Framework Programme (FP7), and will run from January 2012 to June 2015. CycLED is focused on optimising the resource flows for LED products, including the recycling of scarce key metals in LED production. The project also aims to find ways to optimise the reliability and extend the lifetime of LED products. Another project goal is to identify opportunities for reduced resource losses during production, use and recycling. The expected results of the CycLED project include reducing the environmental impacts and costs of LED production and increasing resource efficiency. The project will also promote closed-loop resource management and separate collection of waste LEDs and LED products.

In its 2013 report, the Joint Research Centre outlines six key areas to address the various concerns regarding the supply risks for critical raw materials, including those used in LED production. These include data collection and dissemination to eliminate information gaps regarding the production, trade, use and even pricing of critical materials. Other important areas are investment in primary production and design and innovation (substitution) and the implementation of resource efficiency strategies. Finally, international cooperation to exchange knowledge, and procurement and stockpiling policies aimed at securing the materials supply chain will also play an important role.[8] While highlighting the importance of action to secure Europe's supplies of critical resources the JRC nevertheless introduces a note of optimism by stressing that the risks of raw materials bottlenecks for key decarbonisation technologies should not be overstated, as numerous risk mitigation options exist.

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SETIS TALKS TO:

Michel Cauwe

Senior Vice-President of Umicore's Thin Film Products business unit

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What are some of the advantages (and disadvantages) of thin film Photovoltaic (PV) technologies over the more conventional crystalline silicon panels that make up most of the market?

M.C.: "Just to put things into perspective, conventional crystalline silicon (c-Si)-based PV now makes up approximately 90% of the market. On average, from 1980-2013 the market share of thin film PV has always been only around 10%. There have been a few cycles, though, where the market share went up to some 15% – most recently around 2008-2009. Most people, including decision-makers, wrongly focus on these short upswings in the market share of thin film PV.

One of the main advantages of thin film PV (TF-PV) technologies is that most of them yield a larger kilowatt-hour (kWh) / kilowatt peak (kWp) output, making their levelised cost of electricity (LCOE) potentially lower. This is in part due to the lower temperature coefficient for the corresponding PV cells, but is also related to the exact sunlight spectrum that is effectively absorbed by the cell – what we call 'band-gap tuning'.

Secondly, thin film PV technologies have, in general, a much lower material balance (the ratio of input to output) and therefore use fewer natural resources. This is particularly the case for thin-film silicon, where – mainly for rigid, glass based modules – only abundant materials, like silicon and aluminium, are used.

Thirdly, TF-PV technologies can produce PV modules directly, by 'monolithic integration' of the cells, where the connections are created **in situ** and the cells created on a glass substrate or superstrate. This makes the module manufacturing much simpler, and cheaper.

As for the disadvantages – none, or almost none of the TF-PV technologies have reached the economies of scale of their crystalline-silicon counterparts. In c-Si manufacturing, the leading (Chinese) cell- and module-makers have capacities of about 2.5 – 3.5 GWp and are loaded to at least 90%. No TF-PV manufacturing operates in that league. This lack of economies of scale makes it more expensive to produce TF-PV modules today.

TF-PV always requires large-area vacuum deposition systems, to deposit the thin layers. Such systems carry high investment costs, which give rise to low machine costs (in terms of depreciation and maintenance) only when they are fully loaded – and for very large deposition systems. In other words, large glass/film unit areas, or high deposition speeds.

Another disadvantage is that all TF-PV technologies have lower conversion efficiencies than their c-Si counterparts. This means that more area is needed for a given rated power (Wp). This has an effect both on the cost of the module – a greater substrate area and a greater area of relatively expensive encapsulation materials – and on the cost of the balance of systems (BOS), such as module mounting systems. This means that the PV system cost per kWp easily gets higher than for c-Si PV systems. And although the higher energy yield (kWh/kWp) often makes up for this higher system cost, it remains a difficult message to the market, and is not easily understood by most people who are not specialised in the technology."

Thin film technologies are particularly suited for applications in Building Integrated PV (BIPV). Could you say more about these exciting applications?

M.C.: "Our view on this is that only roof-integrated PV really makes economic sense. PV facades intrinsically have a low energy yield (kWh/kWp) due to their limited insolation (low average angle of light incidence). For roof integration, BIPV means that the PV-panel itself is the roofing material (or is intimately connected, or conformal, with it). Only flexible PV modules can really result in such an integration. This limits the available technologies to flexible TF-PV, unless c-Si wafers, on which c-Si cells are made, become so thin that they are flexible.

A roofing material can be flexible or rigid and can, for example, be ceramic tiles or standing seam metal roofing. But first of all it

has to provide shelter against the weather. Nobody wants a leaky roof. This, together with the conservatism of the building industry, means that the flexible modules themselves cannot really act as the roofing material as such. They have to be attached, for example by gluing, to safe (i.e. certified) roofing materials that already have a proven track record.

There is still quite some development needed to assure a lifetime of, say, 30 years (typically 50 years in Europe) for such integrated products. This means that, today, BIPV is less than 1% of the overall yearly PV market. Only in advanced architecture, where people are deliberately spending money to have something special, or in areas of the world where there have been more interesting incentives for BIPV (such as France, for a short period of time), has BIPV really been used. ”

A few years ago thin film technologies for PV applications were seen as a breakthrough for the PV industry. But the market didn't seem to materialise as expected and several start-ups went out of business. What is the state of play today?

M.C.: “ The reality today is that c-Si PV modules are sold in the market at a price of USD 0.60–0.80/Wp,[1] even with a small profit. Any new or other technology which aims to enter the market in 2-3 years from now must be able to prove a PV module sales price potential (not cost!) at that time of some USD 0.40-0.50 /Wp.[1] This is not so easy to do. To my surprise, new start-ups in TF-PV are still launching product developments without a realistic view of their cost potential, although much less than a few years ago.

But, in my opinion, the real future is in the combination of thin film technology and crystalline Si technology. We are already seeing the success of 'rearside passivated' c-Si cells with higher cell efficiencies (so-called PERC, PERL and PERT cells). But all the advantages of both technology groups come together uniquely in what are known as hetero-junction a-Si/c-Si cells. The nice thing about those cells is that they can be produced with a very low thermal budget – the maximum manufacturing temperature being around 200°C. This makes it possible to use very thin silicon wafers, maybe less than 100 µm thick. Modules made with such cells have a cost potential below USD 0.40[1] /Wp, even if an indium-based transparent conducting oxide is needed.

Also, the temperature coefficient of such cells is lower than for standard c-Si cells, which should result in higher PV-system energy output (kWh/kWp). You will see this family of products developing strongly over the next 3-5 years. ”

Some critics have said that thin film PV will remain a niche market. Do you agree?

In the short to mid-term (horizon 5 years), we agree. However, there are still a lot of developments on the horizon that can completely reshape the landscape in the long term. Here, we are referring to copper-zinc-tin-sulphide (CZTS) as a replacement for copper-indium-gallium-(di)selenide (CIGS) – an absorber that uses only abundant elements with lower cost – to perovskites or the use of quantum dots. Each of these has the intrinsic potential to completely turn the situation around. ”

What part do you think thin film PV can play in helping to achieve the EU SET-Plan targets for low-carbon energy for 2020 and beyond?

M.C.: “ Referring to what I said earlier, thin-film will be approximately 10% of the total share of PV. TF-PV will be used less in BIPV – as there are almost no flexible TF-PV products left on the market – but mainly in roof-top and ground mounted, grid-connected systems. The higher kWh/kWp potential will become more important, especially in Southern Europe where grid parity is becoming a reality, provided the kWp cost is not too far off from c-Si PV systems. ”

1. USD 1.00 = EUR 0.82 - December 2014

Michel Cauwe

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SETIS FEATURE ARTICLE

Substitution: when necessity is the mother of invention

China's monopoly over rare earth ores for the permanent magnets used in some wind turbines has prompted the search for cutting-edge alternatives

Wind power could meet around 15 % of EU electricity consumption by 2020, according to a 2014 report by the European Wind Energy Association (EWEA), achieving a total installed capacity of 192.4 GW.[1] Offshore installations will account for around 23.5 GW of this total. These impressive figures are largely thanks to a revolution in turbine technology a decade or so ago, which allowed the offshore wind industry to become commercially viable. Today the industry is looking for yet another technology revolution to sustain its future growth.

While onshore wind is likely to dominate the sector for a long time, in Europe at least, the technology relies mostly on relatively slow and heavy, geared turbines that convert mechanical energy to electricity through electro-magnets, using copper induction coils. The weight, relatively low efficiency and heavy maintenance requirements of this technology mean that it is not ideal for offshore installations.

At the beginning of the last decade, the development of direct drive turbines that dispensed with the heavy copper wire and gearing used in electromagnets was hailed as a breakthrough in turbine technology. These turbines use permanent magnets containing an alloy of so-called 'heavy-group' rare earth metals (neodymium and

dysprosium), together with iron and boron. Neodymium-iron-boron alloys make the strongest known magnets and, when dysprosium is added, can operate at very high temperatures (over 100 degrees Celsius). These magnets are used in magnetic resonance imaging (MRI) machines – and miniature versions make cell phones vibrate when they receive a call. They are lightweight and resilient, making them ideal for offshore use, where they allow direct-drive turbines to rotate at higher speeds and temperatures, and require significantly less maintenance than electromagnet-based turbines. Also, a decade ago, high copper prices made the (then) relatively cheap rare earth permanent magnets especially attractive.

By the end of the decade, though, just when technological innovations in turbine design had started to bring down the cost of offshore wind installations, a crisis developed in the supply of dysprosium and neodymium. Around 90 % of the known global reserves of these rare earths are found in China, giving that country a virtual monopoly – not only of the raw materials, but also of the technology to mine them and to manufacture the magnets. Keen to protect its expanding domestic wind energy market and maintain its position as a leading global turbine manufacturer, China imposed export restrictions on rare earth metals and also repatriated the magnet manufacturing technology.

As a result, prices of the rare earth ores – and hence the permanent magnets – rocketed, reaching a peak in 2011 at about 100 times their price in 2002-3. Although prices quickly dropped again, stabilising at about 2–3 times their pre-crisis level, the uncertainty in the supply chain prompted European and US manufacturers, who feel particularly vulnerable to China's monopoly, to search once again for new turbine technologies that do not rely on rare earth permanent magnets.

Under the EC Seventh Framework programme (FP7), 15 European research centres and manufacturers – with external advisors in Japan and USA –joined forces in 2012 in a consortium that aims to reduce Europe's dependence on imports of rare earth magnets and raw materials from China. Called ROMEO (Replacement and Original Magnet Engineering Options), the project has two phases. The initial focus is on improving the properties of permanent magnets based on light rare earth elements (i.e. not dysprosium and neodymium) – especially their 'coercivity', or resistance to becoming demagnetised – so that they can be used for applications above 100°C, such as wind turbines. "The second ambitious goal," according to ROMEO's objectives, "is to develop a totally rare-earth free magnet."

Meanwhile, another FP7 project, Suprapower, aims to completely sidestep wind turbines based on the use of permanent magnets by developing a "superconducting, reliable, lightweight and more powerful offshore wind turbine." This innovative project is not only driven by the need to find an alternative to Chinese rare earth-based magnets, though. The consortium of European research centres and manufacturers also claims that existing geared and direct-drive turbine technologies cannot easily be scaled up beyond their present 10 MW power ceiling. "Their huge size and weight", says the project's latest progress report,[2] "drives up the cost of both fixed and floating foundations, as well as operation and maintenance costs." Superconductivity, believe the consortium partners, will allow scaling even beyond 10 MW "by a radical reduction of the head mass."

Suprapower's superconducting direct drive generator exploits the superconducting properties of magnesium diboride (MgB_2) wires – already used in the coils of commercial MRI systems. It will weigh about 200 tonnes with a power of 10 MW and a rated speed of 10 rpm. According to the project's report, the new design should be 30 % lighter than current alternatives. Once tested, the prototype will pave the way for developing large generators of 10, 15 or even 20 MW, "up to the power and load level approaching the aerodynamic limit of the [rotor] blades."

Outside Europe, other manufacturers, such as US-based GE Power Conversion and AMSC have also been testing 10 MW direct-drive turbines based on high temperature superconductors. And, perhaps frightened by its own rare-earth shadow, China's own turbine manufacturers XEMC and Dongfang have also been looking for alternative designs that do not rely on permanent magnets. Although mostly servicing China's domestic market, XEMC has installed a prototype 5 MW direct drive offshore turbine in the Dutch province of North Holland, using copper coils and electrical excitation. Ironically, the high price of copper was originally one of the reasons for developing rare earth permanent magnets in the first place, but it is now cheaper, with a more predictable supply chain.

1. http://www.ewea.org/publications/reports/wind-energy-scenarios-for-2020/
2. http://www.suprapower-fp7.eu/docs.php

Can substitution address raw material supply bottlenecks in green technologies?

Securing sustainable access to raw materials has increasingly become a key strategy for the European Commission in recent years. In particular, critical metals like rare earths (neodymium, dysprosium, europium, terbium, etc.) and other metals such as gallium, indium, germanium have become the focus of politics, economics and science in Europe. Their unique properties make them important components of numerous high-tech applications and green technologies. Many of these applications make it possible to create technologies that fulfil several of the EU's important goals, like reducing greenhouse gas emissions. Simultaneously, these applications and their embedded critical metals secure the relevant innovative industries in Europe – renewable energy production, the automotive industry, the electronics industry etc. – which, in turn, guarantees economic development, safeguarding of jobs and competitiveness in a globalized world. Important sustainable strategies to address bottlenecks in the supply of critical metals are:

- Higher material efficiency;
- Reuse, recycling and waste reduction;
- Increasing European mine production or by-product extraction;
- Substitution.

All four strategies are required in equal measure, as they each have their specific limitations.

Two examples of significant improvements in material efficiency are a reduction of the dysprosium used in permanent magnets and a reduction of the lanthanum used in refinery catalysts, as a response to the rare earth crisis. The fact that both these moves towards higher material efficiencies were implemented in the space of one to three years proves that industries have a strong innovation drive. Nevertheless, this success will not be sufficient to meet the long-term significant increase in dysprosium demand.

Recycling cannot provide large secondary raw material volumes in the short-term since the raw materials will only enter the recycling circuit many years later. Consequently, recycling is an important strategy for a secure long-term raw material supply but not an appropriate instrument to cope with short- and mid-term supply shortages.

Implementation of sustainable primary production chains is an ambitious goal for the EU because mining currently takes place in a highly competitive international market, often with insufficient environmental and social standards in many mining countries. Furthermore, the international mining business is dominated by non-European countries, while European industries mainly focus on manufacturing at the other end of the value chain.

These circumstances make substitution an essential European strategy for securing its raw material supply, particularly as Europe's industries have the innovative capacity to successfully develop and implement substitutes. One further effect is that the development of new substitutes opens new market opportunities in the green technologies sector.

One example of the rapid development of substitutes is the fast market penetration of LEDs. At the beginning of 2011, the state of the art for lighting technology was fluorescent lamps and LEDs only had a small market share. There was no substitute available for rare earths in phosphors. Just two and a half years later the world is witnessing rapid growth in the market share of LEDs. There are even rare earth-free LEDs commercially available. This rapid technological leap occurred surprisingly quickly and illustrates the innovative potential of European and global industries in business areas with high market volumes.

The table below gives an overview of certain green technologies needing critical raw materials, and highlights potential substitution strategies that are already implemented or currently in development.

Substitution is clearly a complex issue. First of all, there are only a few one-to-one material substitutions. Instead, a partial application of new technologies and processes is necessary, for example drives with gears in wind turbines substitute direct-drives. Other substitutions even include the whole system, i.e. the application of LED lamps instead of fluorescent lamps.

Additional important aspects of substitution address the specific technical requirements that should be met. For example, electric

motor types without rare earths are available as substitutes and are successfully used in some electric vehicles. However, these substitutes need more space, making their use difficult in hybrid electric cars. Therefore, car manufacturers report that they favour compact electric motors with permanent magnets in hybrid electric vehicles.

critical material, but its production may cause significant water and air emissions because many mines and refineries around the world operate using equipment with insufficiently high environmental standards. Consequently, sustainable substitution strategies should always include the sustainable production of the substitute.

Technology	Critical Element	Potential or Possible Substitution	Substitution Leading to Higher Demand of:
Electric drive motors for EVs	Neodymium, praseodymium, dysprosium	Alternative motor types without REE	Copper, ferrite
Direct-drive wind turbines for offshore plants	Neodymium, praseodymium, dysprosium	Traditional turbines with gear	Copper
Photovoltaics with thin film technology	Indium, gallium	Silicon-based cells, cadmium-tellurium-cell	Silicon, cadmium, tellurium, gallium arsenide
Li-ion batteries	Cobalt	cobalt-manganese-nickel compound	Manganese, nickel
LEDs	Gallium, indium, rare earth	Organic-based liquid crystals and organic based LED	Zinc, Magnesium, Indium-Tin-Oxide, various metallo-organic compounds, silicon based nanoparticles
Fluorescent lamps	Rare earth, gallium	LED	LED has a much higher material efficiency for all compounds
Autocatalysts, specific industrial catalysts	Platinum group metals	No adequate substitution available	
Nickel-metal-hybrid batteries	Rare earths, cobalt	Li-ion batteries	Lithium, cobalt, manganese, nickel

Table: Selected green technologies and their associated critical elements and substitution potentials

Thin film solar technology further illustrates the relevance of technological aspects of substitution. The flat solar panels used for thin film technology allow for lightweight constructions, which offer a wide range of architectural design opportunities in contrast to the heavier traditional silicon-based solar panels that require a more stable underframe.

The environmental impact of substitution should also be carefully considered, since the environmental footprint of alternative substitutes must be calculated. For example, wind turbines without rare earths require significantly more copper. Copper is not seen as a

Overall, substitution is seen as an essential European strategy to secure raw material supply for green technologies and decarbonisation. Implementation is complex due to the wide range of applications of critical raw materials, their substitutes and their specific technical requirements. As a result, the implementation of substitution involves many sectors and stakeholders at all levels of national and international action. The EU has recognized the importance of substitution and addresses it within the European Innovative Partnerships (EIP), the 7th European research framework program and JRC's research activities.

Doris Schüler

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Making the materials to drive Europe's energy revolution

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Europe's energy system is changing profoundly. The share of renewable and decentralised energy in the energy mix is foreseen to increase. At the same time, overall energy efficiency should improve well beyond the 2020 objectives. This poses exciting challenges for a massive roll out of low-carbon energy technologies and the large scale installation of energy efficient solutions. Advanced materials and manufacturing will be the key enablers to realise these goals. Not only will we need a wide range of advanced materials in sufficiently large quantities to modernise energy installations in the short and medium term, but we should also invest for the future: it can easily take between 15 to 20 years of R&I activity before a new material is developed and ready for market uptake, becoming an every-day component of an energy technology.

The markets are there!

In a recent study ordered by the European Commission[1], close to 40% of the interviewed venture capitalists and private equity investors were willing to invest early stage or seed capital in advanced materials dedicated to the energy sector. Perhaps surprisingly, this was substantially higher than their willingness to invest in materials for applications in the ICT, transport, health or environment sectors which were also covered by the study. The total worldwide market value for advanced materials, estimated to be EUR 100 billion in 2008, is projected to grow to an astonishing EUR 1100 billion by 2050. The market share of advanced materials for energy applications is thereby expected to increase from EUR 7 billion (7% of the total market value) in 2008 to almost EUR 176 billion (or 16% or the total market value). Only advanced materials to tackle environmental problems such as air pollution or water treatment are expected to have stronger growth.

Advanced materials raise (and fulfil!) high expectations

The times that only a few materials such as steel, copper and concrete were the main components for energy technologies are long gone. The JRC identified no less than 60 metals which are vital for the different energy technologies covered by the SET-Plan[2]. And such advanced materials are known to drive innovation: some 70% of all technical innovations can be directly or indirectly attributed to the materials they use. The impact of advanced materials (measured as the fraction of growth that can be attributed to advanced materials) for the energy sector, is steadily growing from 10% in 1970 to an expected 70% in 2030[3]. It is therefore no surprise that strategic research agendas for most energy technologies strongly depend on the performance of the materials to be used in future applications. In particular for the SET-Plan low-carbon energy technologies, the European Commission published recently a Technical Roadmap to establish exactly what materials are needed in order to drive the next generation power sources or to make buildings more energy efficient[4].

From lab to industry to market

The willingness to invest and a solid research agenda alone are not enough to make these materials. Advanced materials and manufacturing are key enabling technologies in which Europe has a leading position in research but is also at the top of the patent ranking. However, a large gap appears between the technology base and the industrial uptake. In particular, long, capital-intensive development times in combination with substantial technology and commercialisation risks make it very difficult for a new material to make it from the laboratory to industrial scale production, and then to the markets. The European Commission can help compa-

nies to safely cross this critical development phase, also known as the Valley of Death.

To do so, almost one year ago, the European Commission launched Horizon 2020, the biggest EU research and innovation funding programme with a total budget of almost EUR 80 billion that will run for 7 years until 2020. Of this amount, EUR 17 billion is reserved in the Industrial Leadership pillar to invest in promising and strategic industrial technologies, to encourage businesses to invest more in research and to cooperate with the public sector, in order to boost innovation. In addition, more than EUR 5 billion is available to invest in R&I to promote the Societal Challenge on Secure, Clean and Efficient Energy. A significant part of this budget is, and will continue to be, used to advance materials technologies for energy applications. Technology-focused product development is funded to help companies drive their innovation from the early stages of development, through the validation and demonstration of concepts and prototypes or pilot lines, towards market acceptance. An integrated approach is adopted with careful consideration of standards and certification procedures. Initial business and exploitation plans ensure that supply chains are already at an early stage on the radar.

A substantial part of the Horizon 2020 budget is available for risk sharing and risk finance. The goal is to stimulate more investment in R&I, notably by the private sector. Increased funding for R&I is also available from the European Structural & Investment Funds (ESIF). The JRC is performing a regional mapping exercise using the Smart Specialisation Platform. Both energy and new materials emerge as important specialisation fields in many European regions. Researchers are encouraged to seek synergies, such as cumulative funding, with national or regional funding programmes or ESIF, for instance, to create favourable circumstances to roll-out technologies at higher technology readiness levels.

This very complete innovation ecosystem has been fully available since the first calls of Horizon 2020. Call topics have been published for 2014 but also for 2015. Some calls which are currently still open for proposal submission are directly targeting material solutions for specific energy applications. Other calls focus more on upscaling the production of novel materials. Once sufficiently available at competitive prices, such materials could very well find their use in energy technologies. All information on the calls and the proposal submission process are available from the Commission's Participant Portal http://ec.europa.eu/research/participants/portal/desktop/en/home.html

1. "Technology and market perspective for future Value Added Materials", final report from Oxford Research AS, available from http://ec.europa.eu/research/industrial_technologies/pdf/technology-market-perspective_en.pdf .
2. "Critical Metals in Strategic Energy Technologies", R.L. Moss, E. Tzimas , H. Kara, P. Willis and J. Kooroshy, JRC Scientific and Technical Reports (2011).
3. "The Advanced Materials Revolution", S. M. Moskowitz, John Wiley & Sons Inc, (2009).
4. "Materials roadmap enabling low carbon energy technologies", European Commission SEC (2011) 1609.


Courtesy of Julie de Bellaing

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Courtesy of FFG/Karin Gartner

Critical Materials in Energy Technologies

A JRC assessment of raw materials as potential bottlenecks and drivers of innovation in the decarbonisation of the European energy system

Critical materials for the European economy

The EU relies on imports for many of the raw materials that are vital to the strength of European industry and that act as a key enabler of growth and competitiveness in the EU. The global increase in raw material demand, the price volatility for some of these materials and the market distortions imposed by some producer countries have all raised concerns within the EU about securing reliable access to raw material resources.

The main challenge for Europe is to tap the full potential of primary and secondary materials through the creation of a pan-European raw materials knowledge base; developing innovative sustainable technological solutions to access raw materials; and establishing a production-friendly legal framework and economically attractive environment across the EU, taking into account environmental and social aspects.

In response to these concerns, the European Commission established the European Innovation Partnership (EIP) on Raw Materials[1]. Its aim is to promote both technological and non-technological innovation along the entire value chain of raw materials (i.e. raw materials knowledge base, exploration, licensing, extraction, processing, refining, re-use, recycling, substitution) involving stakeholders from relevant upstream and downstream sectors. The JRC provides scientific support to enable the Commission to implement the monitoring and evaluation scheme of the EIP on Raw Materials.

Another measure is the instigation of the Raw Materials Initiative[2] to help the EU develop a common approach on raw materials issues. Among the actions taken is the regular publication of a list of 'critical' raw materials, which can be used to identify priority actions. This list identifies materials of high economic importance to the EU, which have a high risk associated with their supply. In the most recent critical raw materials list, compiled in 2014[3], twenty raw materials from a list of 54 potential candidates have been identified as critical. These are: antimony, beryllium, borates, chromium, cobalt, coking coal, fluorspar, gallium, germanium, indium, magnesite, magnesium, graphite, niobium, platinum group metals, phosphate rock, rare earth elements, silicon and tungsten.

The importance of raw materials for the energy sector

The transition to a low-carbon economy, a central priority of the EU, necessitates the large-scale deployment of energy technologies that can significantly reduce the carbon footprint across the energy system, such as wind, solar photovoltaics, nuclear fission and carbon capture and storage in power generation; electric vehicles in transport; and more efficient appliances and lighting to reduce energy demand. It is frequently overlooked that vital components of these energy technologies are manufactured from imported raw materials. For example, some rare earth elements (REE) such as neodymium (Nd), dysprosium (Dy) and praseodymium (Pr), are key ingredients of permanent magnets used in high-performance wind turbines and electric vehicles. These raw materials are currently only produced in China and their exports are regulated. The following figures illustrate the magnitude of the challenge that may lie ahead. A typical 3 MW wind turbine may contain 120 kg of neodymium in the permanent magnet of the generator; while an electric vehicle may contain from 0.4 kg of neodymium (in a

mild hybrid electric vehicle) to 2.6 kg (in a battery electric vehicle). Scenarios for the decarbonisation of the European energy system indicate that about 350 GW of wind energy and 60 million electric vehicles could be deployed in Europe by 2030. The demand for neodymium by the European energy system alone could then reach about 8000 tonnes in 2030, which is about one third of the current annual global production or about 10% of the projected production of neodymium in 2030. The supply of neodymium will also be targeted by other regions of the world, which will also deploy low-carbon energy technologies, and by other applications, such as ICT, thus intensifying the challenge.

The JRC analysis

The JRC has been carrying out regular analysis to identify the raw materials that could become a bottleneck in the supply chain of various low-carbon energy technologies[4]. The JRC methodology follows a three-step approach, which is illustrated in Fig.1:

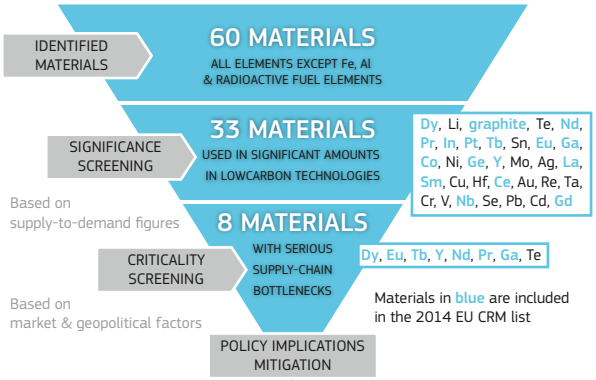


Fig.1: The JRC methodology for the identification of critical materials for the European energy sector.

- Materials inventory: An inventory of raw materials used in the manufacture of energy technologies is compiled and quantified. The latest JRC analysis, published in 2013, identified 60 raw materials that are used in low-carbon energy technologies (this list does not include construction materials such as iron and aluminium, and fuels).
- Significance screening: The current and forecasted demand for each raw material in the inventory, taking into consideration anticipated technology developments and technology deployment scenarios, is compared to current and future materials supply. Figure 2 shows a sample of results from this significance screening. The forecast demand for six raw materials used extensively by the European energy sector: dysprosium (Dy), lithium (Li), graphite, tellurium (Te), neodymium (Nd) and indium (In) ranges between 6% and 26% of global supply. Moreover, with the exception of Li, China is the main producer these materials; and for four of them China dominates global supply.
- Criticality screening: The raw materials, for which the ratio of EU demand for energy applications to global supply exceeds a given threshold, as calculated during the significance screening, are further evaluated to identify the critical materials for the EU energy sector. This assessment is based on market factors (i.e. limitations to expanding supply capacity and the likelihood of rapid global demand growth) and geopolitical factors (cross-country concentration of supply and political risk related to major supplying countries).

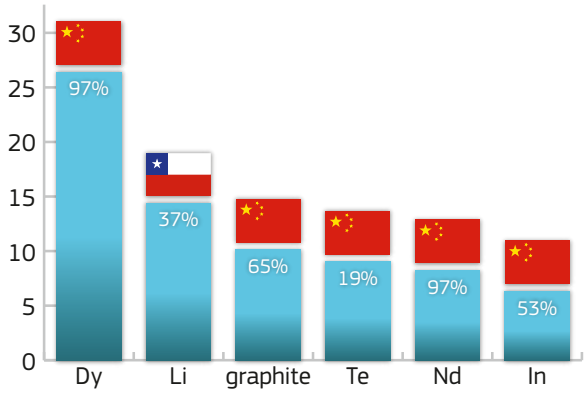


Fig. 2: Ratio of future demand from the EU energy sector to global supply (%) for 6 materials with expected wide usage in energy technologies. The graph also indicates the largest producing country and its share in global production.

Eight metals were classified as 'critical'. These include six REEs (dysprosium (Dy), europium (Eu), terbium (Tb), yttrium (Y), praseodymium (Pr) and neodymium (Nd)), as well as gallium (Ga) and tellurium (Te). Six materials were classified as 'near critical' (graphite, rhenium (Re), hafnium (Hf), germanium (Ge), platinum (Pt) and indium (In)) implying that their market conditions should be monitored closely. The results are summarised in Table 1.

According to the JRC analysis, the technologies that are most vulnerable to potential disruptions of raw materials supply are (Fig. 3):

- Lighting: State-of-the-art lighting uses four critical materials (three REEs used in phosphors: Y, Tb, Eu, and Ga) and two near-critical materials: Ge and In.
- Wind energy and electric vehicles use 3 critical raw materials for permanent magnets: the REEs Dy, Nd and Pr. Furthermore, electric vehicles use the near-critical graphite in the battery packs.
- Photovoltaics use two critical materials Ga and Te.
- The nuclear industry uses the near-critical materials Hf and In.
- The fossil fuel power sector uses the near critical Re for the production of superalloys.
- Fuel cells use the near-critical Pt as a catalyst.

Raw Material	Risk Rating	Associated Technology
Rare Earths: Dy, Pr, Nd	High	e-vehicles, wind
Rare Earths: Eu, Tb, Y	High	lighting
Gallium	High	lighting, solar
Tellerium	High	solar
Grapghite	Medium-High	e-vehicles
Rhenium	Medium-High	fissil fuels
Halfnium	Medium-High	nuclear
Germanium	Medium-High	lighting
Platinum	Medium-High	fueal cells
Indium	Medium-High	solar, lighting, nuclear

Table 1: Critical materials for the EU energy sector and the technologies affected.

The above classification should be regarded as an indication of possible supply-chain bottlenecks that could occur under business-as-usual conditions, as they are subject to the following uncertainties:

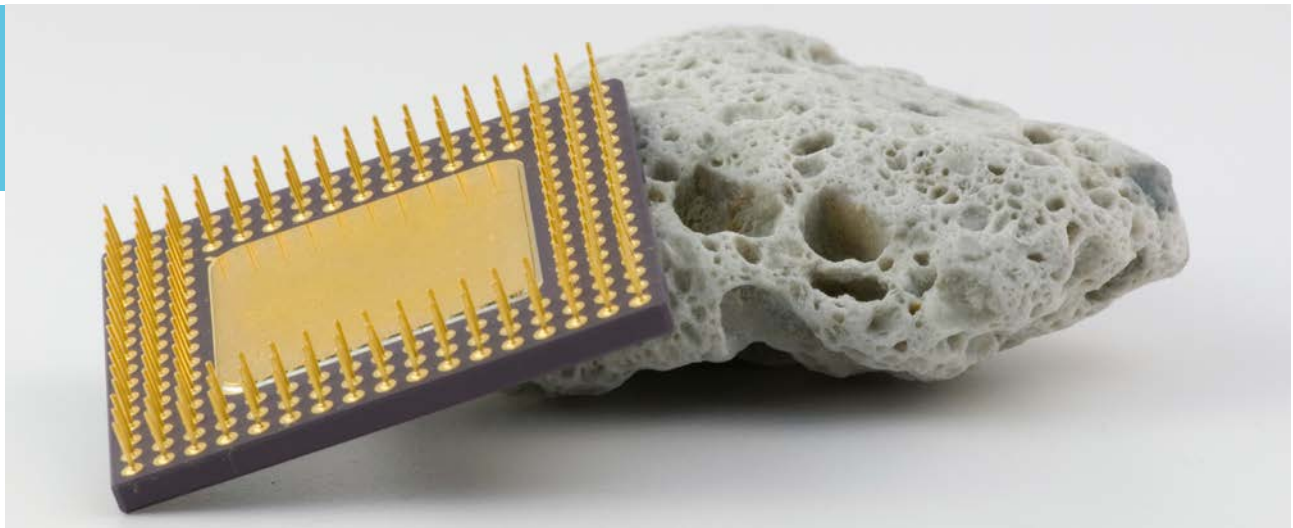
- the penetration of low-carbon technologies;
- the technology mix between competing energy sub-technologies (e.g. wind generator or electric vehicle types);
- the materials composition and associated quantities of some components;
- the substitutability of key materials in certain technologies;
- the projected supply of various metals.

The JRC investigated the sensitivity to these sources of uncertainty for hybrid and electric vehicles and lighting. For hybrid and electric vehicles, the analysis highlighted the sensitivity of the results to REE substitution rates. The share of permanent magnet motors and induction systems in the technology mix was also found to be a key sensitivity, as to some extent was the choice of battery chemistry. For lighting, a key sensitivity was found to be the timing and penetration of LED lighting versus phosphor lighting.

Mitigation of supply risk

The JRC has identified three main avenues to mitigate supply-chain risks for critical materials in the energy sector:

- Increasing primary supply: The development of REE mines within Europe is in its early stages. The Norra Kärr deposit in Sweden is relatively attractive given its high proportion of heavy rare earths. An alternative option in the short term is to process REE concentrates from tailings, by-product sources or from mines opened outside Europe. For gallium and tellurium, the data indicate that Europe already has a degree of self-sufficiency; however, opportunities may exist to create further refineries to boost recovery of these materials.
- Reuse / recycling and waste reduction: Significant improvements have already been made in the recycling of post-industrial waste streams such as magnet, semi-conductor and photovoltaic scrap. Recycling post-consumer waste streams is more challenging due to issues with collecting, sorting and pre-processing, as well as the long lifetimes of certain product groups. Nevertheless, there are short term opportunities and initiatives for the recovery of rare earth magnets from hard disc drives and rare earth phosphors from lighting.
- Substitution: The increased price of these materials has resulted in a significant reduction in materials intensity for some applications, such as the reduction of dysprosium and neodymium in rare earth magnets, or terbium and europium within rare earth phosphors and the minimisation of the thickness of cadmium-tellurium thin films within solar panels. Systemic approaches to materials substitution are also being widely considered including alternative motor technologies as well as alternative lighting technologies e.g. LEDs, OLEDs and quantum dots. There are also opportunities to substitute the current use of critical materials from traditional applications where other materials are suitable e.g. eliminate tellurium from steel alloys. Currently the JRC is carrying out a study to identify substitution



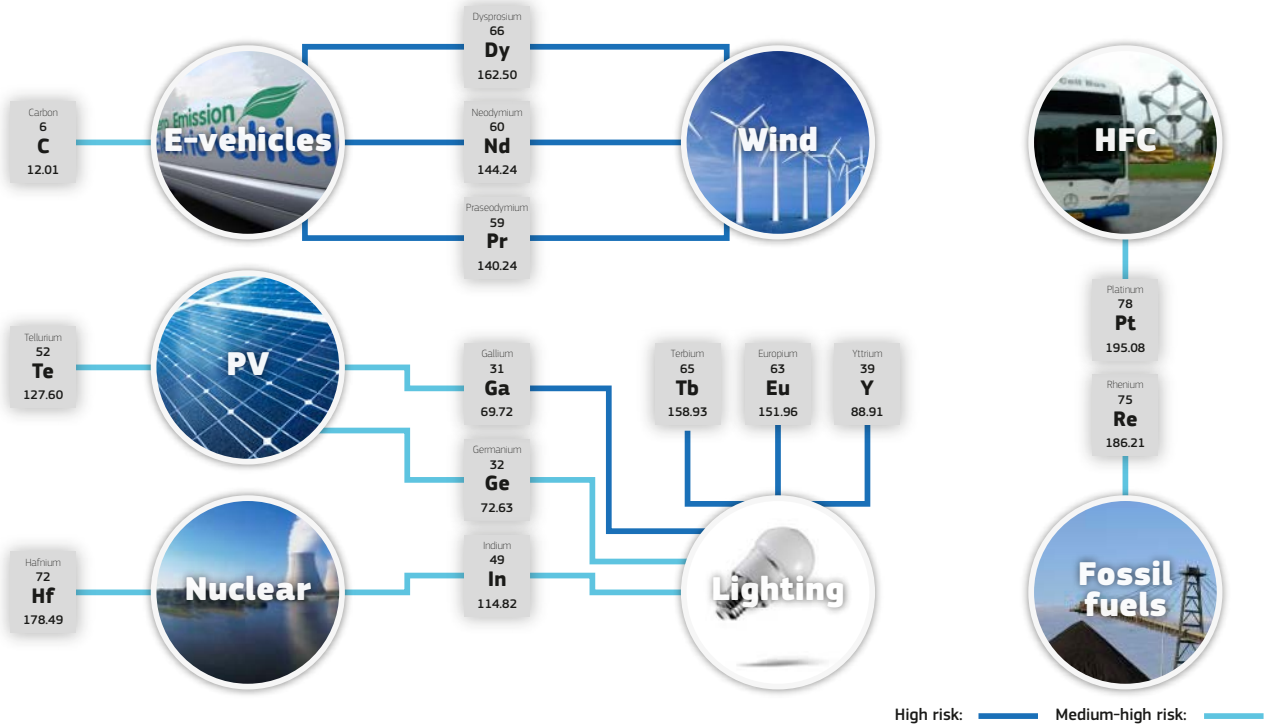


Fig. 3: Energy technologies' vulnerability to potential disruptions of critical and near-critical raw materials. Red lines indicate links to critical materials, and yellow lines to near-critical.

opportunities for critical raw materials used in wind energy, electric vehicle and lighting applications.

Raising awareness

In response to the need for raising public awareness about the important link between raw materials and energy technologies, the JRC developed a Materials Information System (MIS). MIS aims to gather, store and disseminate information about materials that are used in low-carbon energy technologies through a user-friendly, easily navigable web-based system, to improve the knowledge base on raw materials in Europe. MIS aims also to provide a common framework to understand material needs and applications, enable in-depth understanding of the whole material supply chain, and contribute to the early identification of upcoming issues in the supply chain and to the formulation of sound recommendations. A further goal of the MIS is to raise awareness among policymakers, industrial stakeholders, academia and the public. MIS brings together publicly available information on current and future materials supply and demand and the main applications. Its contents are updated regularly based on the outcome of JRC assessments. It can be visited via the SETIS website: http://setis.ec.europa.eu/mis.

1. See https://ec.europa.eu/eip/raw-materials/en
2. See COM(2008) 699 final and COM(2013) 442 final
3. See COM(2014) 297 final
4. See: Critical metals in the path towards the decarbonisation of the EU energy sector (2013), available from: http://setis.ec.europa.eu/publications/jrc-setis-reports/jrc-report-critical-metals-energy-sector

Dr. Evangelos Tzimas

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SETIS FEATURE ARTICLE

Securing Europe's Critical Raw Material supply chain: the role of recycling

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Critical metals are central to a number of technologies that underpin many low-carbon energy systems. In light of the current scarcity of some of these raw materials, the European Commission has classified a list of 20 resources[1] as being of critical importance (EC 2014). There are a number of ways that Europe can reduce its exposure to potential supply bottlenecks for these critical raw materials, including by investing in primary mining and conducting research into the substitution of these materials with more readily available alternatives. The third most important approach is the recovery of raw materials from waste products though 'urban mining' or recycling.

In the report Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector, the Joint Research Centre - the European Commission's in-house science service, highlights the importance of policy measures to increase the reuse, recycling and waste reduction of critical metals with a view to mitigating future potential supply risks. To provide this policy support, the EC set out its vision for Europe as a recycling society in its Communication on the Thematic Strategy on the Prevention and Recycling of Waste (COM/2005/666). This was followed in 2008 by the Raw Materials Initiative (RMI)[2] which established an integrated strategy to respond to the different challenges related to access to non-energy and non-agricultural raw materials.

The RMI is based on three pillars: ensuring a level playing field in access to resources in third countries; fostering sustainable supply of raw materials from European sources, and boosting resource

efficiency and recycling. With regard specifically to waste electrical and electronic equipment (WEEE), which is the main source of recycled critical metals, the first EC Directive (2002/96/EC) came into force in 2003 and aimed to increase the recycling and re-use of WEEE by providing for the creation of collection schemes allowing consumers to return WEEE free of charge. A revised version of this Directive (2012/19/EU) entered into effect at the start of 2014 and aimed to tackle the rapidly increasing waste stream.

According to the United Nations Environmental Programme report Critical Metals for Future Sustainable Technologies and their Recycling Potential, recycling not only increases resource efficiency and reduces the likelihood of supply shortages - it also reduces the overall environmental impact associated with the life cycle of critical metals, as recycling of metals usually has much lower environmental impacts (lower energy demand, greenhouse gas emissions etc.) than the production of primary metals from natural ores.[3] The UNEP report identifies two distinct types of recycling: end-of-life (post-consumer) treatment of waste, and recovery of metals during processing and manufacturing. The latter is an efficiency measure that is frequently incorporated into manufacturing processes, particularly those involving expensive raw materials. The materials recovered in pre-consumer waste are generally easier to exploit, as they are less dispersed and contaminated than in post-consumer waste.

Post-consumer recovery of critical metals is more difficult due to the low metal concentrations in waste flows and the fact that the critical metal is usually a minor composition in a complex material system involving many other metals, plastics etc. Another issue that hampers the recovery of metals from electrical and electronic equipment is the fact that the recovery is often carried out in developing countries where the collection systems in place are sub-optimal. Furthermore, the long lifetimes of many products containing critical metals, and the newness of some of the technologies in question, mean that post-consumer recycling will only be possible in the longer term. Nevertheless, the UNEP report notes that, despite these restrictions, the post-consumer recycling of many critical metals is at an advanced stage thanks to continuous improvements in recycling technologies.

About 3.1 million tonnes of WEEE was reportedly collected in the EU in 2008, but it is estimated that around 7 to 8 million tonnes of WEEE was generated, which implies a collection rate about 40%.[4] The UNEP report estimates the current post-consumer recycling rates for rare earths, gallium and tellurium globally at less than 1%, compared to over 50% for many base and precious metals. Germany's Öko Institute, which produced the report on behalf of UNEP, has identified a set of preconditions for the optimisation of recycling of critical materials. These include enlarging existing recycling capacity and the development and implementation of new recycling technologies. The European Union is addressing this need through projects such as RARE[5], which is focusing on breakthrough recycling processes for permanent magnets and lamp phosphors, which represent over70% of the rare earths market by value. The European Rare Earth (Magnet) Recycling Network[6] was set up in 2013 to train researchers in basic and applied rare-earth sciences, with an emphasis on extraction and separation methods and rare-earth metallurgy, recycling methods and the principles of urban mining. This network aims to ensure that Europe has the human resources required by the growing European rare-earth industry.

The UNEP report also calls for the accelerated improvement of international recycling infrastructures and notes that the main problems with the current recycling of critical metals are the lack of suitable take-back and collecting systems for post-consumer waste flows in most parts of the world. This is fraught with consequent health risks for the people involved in recycling, and significant losses of valuable critical metals. State-of-the-art integrated smelter-refineries can achieve a high recovery yields (over 95% for precious metals with co-recovery of a number of special metals and even of some indium)[7] and innovative dedicated recovery processes for batteries can achieve yields of over 90% for cobalt and also recover lithium. However, less sophisticated end-processing can result in significant losses, and resolving this problem will require the transfer of know-how and technology transfer from the developed world.

A report from the Copenhagen Resource Institute on present and potential future recycling of critical metals in WEEE in Europe shows that, while the current recycling of critical metals in WEEE is very low, this could increase threefold to 3,000 tonnes in 2015. The report notes that the revised WEEE Directive should have a positive impact on recycling of critical metals, with a minimum collection of 45% to be achieved within four years and 65% in seven to nine years. However, the integrated optimization of the whole value chain including product design, collection, dismantling, pre-processing and smelting will be crucial if these targets are to be met.

1. http://europa.eu/rapid/press-release_IP-14-599_en.htm
2. COM(2008) 699 Communication "The raw materials initiative - meeting our critical needs for growth and jobs in Europe".
3. http://www.unep.fr/shared/publications/pdf/DTIx1202xPA-Critical%20Metals%20and%20their%20Recycling%20Potential.pdf
4. http://cri.dk/sites/cri.dk/files/dokumenter/artikler/weee_recycling_paper_oct14.pdf
5. http://kuleuven.rare3.eu/
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