Critical Raw Materials
Innovation Network

February 2015, Dr Susanne Coles
• Critical Raw Materials Innovation Network – Towards an integrated community driving innovation in the field of critical raw material substitution for the benefit of EU industry.
80% of senior executives from global manufacturing companies cite mineral and metals scarcity as a pressing issue *(PWC, Dec 2011)*

67% see this evolving into an area of opportunity, including the possibility of adopting alternative approaches or substitutes *(PWC, Dec 2011)*
EU Critical Raw Materials

Supply Risk

Economic Importance

Rare Earths
PGM
Germanium
Magnesium
Antimony
Gallium
Indium
Beryllium
Fluorspar
Tantalum
Tungsten
Niobium
Graphite

Barytes
Diatomite
Talc
Perlite/Clay
Gypsum/Silver
Borate
Bentonite
Limestone
Copper
Silica
Feldspar
Titanium
Lithium
Boron
Magnesite
Rhenium
Tellurium
Vanadium
Molybdenum
Iron
Zinc
Chromium
Manganese
Electrolytic Nickel
Bauxite
Substitution:

1. Substance for Substance
2. Service for Product
3. Process for Process
4. New Technology for Substance
• What are the raw materials used for?
• Are there alternative materials or technologies?
• What are their relative merits?
Materials mapping

http://www.criticalrawmaterials.eu/documents/
Application-led approach

- Energy
- ICT and Electronics
- Transport (Automotive and Aero)
Supply chain analysis methodology

1. Screening

List of applications -> corresponding statistical product groups

- CRMs are present in the application
- EU production > 25% of the amount consumed in Europe
- Share of application ≥0.2% of the production of the PRODCOM sector

2. Supply chain analysis

Structural composition of selected applications

Statistical analysis
Eurostat PRODCOM
- Total EU and EU country level production, export and import data
- Graphical description: Total production, import and exports, 3 major producing countries

Business analysis
Reports, interviews
- Economic: Economic value for EU, jobs, main actors
- Criticality: CRMs involved, future development, CRM function, availability + status of substitutes
- Strategic: Value for European strategies
Applications for Supply Chain Analysis

Energy
• Wind power
• Thin film Photovoltaics
• Energy storage

Electronics and ICT
• Optical fibre
• Flat panel displays and screens
• Magnetic Resonance Imaging
• LED lighting
• Washing machine
• Assembled Printed Circuit Board

Transport
• Automobile
• Heavy vehicle
• Commercial airplane

http://www.criticalrawmaterials.eu/documents/
Supply chain analysis of LED-lighting: decomposition

Raw-material
- Be in ore or partly refined
- Ga in ore or partly refined
- Ge in ore or partly refined
- Nd in ore or partly refined
- Ta in ore or partly refined
- Ru in ore or partly refined
- Pt in ore or partly refined
- Ga in ore or partly refined
- In in ore or partly refined
- Ce, Y, Tb, Eu, Gd in ore or partly refined

Material/alloy
- Beryllium
- Gallium and germanium
- Compounds of rare earth metals
- Tantalum
- Platinum group metals
- Gallium and indium
- Compounds of rare earth metals

Sub-component
- Connectors
- Transistors
- Capacitors
- Resistors
- Bare printed circuit board
- Semiconductor
- Luminescent powder

Component
- Assembled printed circuit board
- LED (light emitting diode)

End application
- LED-lighting

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Substitution of Critical Raw Materials
Top three producing countries

- Assembled printed circuit board
  - Transistors (1:DE, 2:UK, 3:FR)
  - Resistors (1:IT, 2:DE, 3:FR)
  - Capacitors (1:IT, 2:DE, 3:FI)
  - Gallium, beryllium, indium and germanium (1:DE, 2:FR, 3:UK)
  - Platinum group metals (1:DE, 2:UK, 3:AT)
  - Tantalum (1:DE)
  - Compounds of rare earth metals (1:DE, 2:EE, 3:FR)

- LED + other lighting (1:DE, 2:FR, 3:IT)
  - 7.0 b€

- LED lighting
  - 1.0 b€

- Connectors (1:DE, 2:FR, 3:IT)
  - Resistors (1:DE, 2:IT, 3:FR)
  - Bare printed circuit board (1:DE, 2:IT, 3:FR)

- Semiconductor light emitting diodes (LED) (1:DE, 2:FR, 3:UK)

- Luminescent powder

Largest producing country
Second largest producing country
Third largest producing country
Position of Europe in LED supply chain

- **Mining/secondary raw material**
  - REE, In and Ga production from primary and secondary sources
  - Umicore
  - Rhodia
  - GEO gallium
  - Johnson Mattehey Ltd.

- **Separation**
  - Nanjing Germanium Factory
  - Huludao Zinc
  - Zhuzhou Smelter Group
  - Dowa Metals & Mining Co.
  - Asahi Pretec Corp.
  - Mitsubishi Mat. Group
  - Korea Zinc
  - Teck Resources Ltd
  - Xstrata Plc.
  - Doe Run
  - China Minmetals Corporation
  - Baotou Steel
  - Guangdong Zhiyuan Rare Earth Co., Ltd
  - Chinalco
  - Sumitomo Chemicals
  - Dowa Mining
  - Indium Corporation

- **Refining or reduction**
  - Over 95% of REE production is in China
  - China produces 55% of In production in 2012

- **Manufacturing and component suppliers**
  - Phillips Lumileds
  - Nichia Corporation
  - Seoul Semiconductor Co., Ltd
  - Cree
  - LUX
  - Edison Opto Corporation
  - Epistar Corp
  - Everlight Electronics Co. Ltd.
  - Kingbright
  - Optogan

- **LED companies**
  - Osram Opto Semiconductor
  - Optogan
  - Valtavalo
  - Umicore N°1 secondary Indium producer in EU

- **Recycling**
  - Recycling end of life products
  - Two EU companies in TOP 5 global LED lighting manufacturers
  - No LED recycling yet in EU

- **Europe**
  - Osram
  - Philips Lighting
  - Havells-Sylvania
  - GE Lighting
  - Megaman
  - Tridonic Atco
  - Valtavalo

- **North America**
  - Nanjing Germanium Factory
  - Huludao Zinc
  - Zhuzhou Smelter Group
  - Dowa Metals & Mining Co.
  - Asahi Pretec Corp.
  - Mitsubishi Mat. Group
  - Korea Zinc
  - Teck Resources Ltd
  - Xstrata Plc.
  - Doe Run
  - China Minmetals Corporation
  - Baotou Steel
  - Guangdong Zhiyuan Rare Earth Co., Ltd
  - Chinalco
  - Sumitomo Chemicals
  - Dowa Mining
  - Indium Corporation

- **Asia**
  - Nanjing Germanium Factory
  - Huludao Zinc
  - Zhuzhou Smelter Group
  - Dowa Metals & Mining Co.
  - Asahi Pretec Corp.
  - Mitsubishi Mat. Group
  - Korea Zinc
  - Teck Resources Ltd
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  - Doe Run
  - China Minmetals Corporation
  - Baotou Steel
  - Guangdong Zhiyuan Rare Earth Co., Ltd
  - Chinalco
  - Sumitomo Chemicals
  - Dowa Mining
  - Indium Corporation

- **REE, In and Ga production from primary and secondary sources**
  - REE production concentrated in China
  - Umicore (Indium) & Rhodia (REE) recyclers

- **Manufacturing of Light emitting diodes (LED)**
  - Over 95% of REE production is in China
  - China produces 55% of In production in 2012

- **The assembly of LED lighting systems and marketing**
  - GE Lighting
  - Samsung LED
  - Nichia Corporation
  - Epistar
  - Toyoda Gosei
  - Cree
  - Toshiba Corporation
  - Sharp corporation
  - LG Electronics

- **Recycling end of life products**
  - Osram, Philips lighting and Havells-Sylvania accounted 62% of EU sales in 2012

Gallium is a by-product of aluminium refining process
## Summary of Europe’s position in supply chains

<table>
<thead>
<tr>
<th>Supply chain</th>
<th>Application/component/material</th>
<th>MRI</th>
<th>LED</th>
<th>Optical fibre</th>
<th>Displays and screens</th>
<th>Washing machine</th>
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<tr>
<td>End product</td>
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<td>Electric motor</td>
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<td>Sub-component</td>
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<td>Transistors</td>
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<td>Bare printed circuit board</td>
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<td>Connectors</td>
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<td>Permanent magnet</td>
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<td>Conducting electrodes (ITO)</td>
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<td>Fluorescent tubes</td>
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<td></td>
<td>Semiconductor light-emitting diodes (LED)</td>
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<tr>
<td>Material</td>
<td>Compounds of rare earth metals</td>
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<td></td>
<td>Tantalum</td>
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<td></td>
<td>Beryllium, gallium, germanium, indium and niobium</td>
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<td>Platinum group metals</td>
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</table>

- Europe strong in end products
- EU production 60-80% of European demand
- Relatively strong in electronic components
Industry Perspective: Challenges and Opportunities

### Advantages of CRM (functionality)
- High degree of storable magnetic energy
- High temperature resistance
- Weight savings which leads to higher efficiency
- Low maintenance requirements
- Usage for metal refining
- Superconductivity

### Reasons for CRM evaluation
- Essential for functionality
- Fluctuations in prices
- Mining will become more expensive
- High political influences (e.g., export quotas)
- Increasing demand due to new technologies/emerging nations
- Dependence on monopoly status of supplier

### Risk management measures are necessary

1. **Substitution**
   - Difficult direct substitution with same functionality:
     - Lower degree of temperature resistance
     - Lower degree of magnetization
     - Long adaptation phases
   - Substitution with other CRMs
   - Multifunctional teams evaluate technologies early on, in a cross-disciplinary approach (engineering/procurement/manufacturing)
   - Not just replacement of materials → functional/system view
   - Long-term planning necessary (several years)

2. **Sourcing**
   - Joint-ventures with suppliers
   - Differentiation between critical and non-critical materials with adapted strategies
   - Long-term agreements with suppliers
   - Specific requirements to suppliers regarding content of components
   - Global sourcing

3. **Recycling**
   - Research collaborations with external partners from public and private sector
   - Refurbishing/exchanging parts of large industrial equipment
   - Great challenge because:
     - Different materials melted together
     - CRM are used in small quantities
   - Mostly downcycling → further research necessary to obtain same quality

4. **Other measures**
   - International alliances
   - EU/national ministry supported research cooperation
   - Analysis of systems, purchasing and delivery
   - Market monitoring
   - Internal multifunctional teams and studies
   - Involvement of suppliers and customers early on
   - Reduction of consumption (limited, otherwise loss of functionality)
Materials Mapping: current substitution technologies and initiatives

Prioritisation of applications under threat

Application Mapping: current substitution technologies and initiatives

Roadmap for critical raw materials substitution

Policy recommendations

CRM_InnoNet Substitution of Critical Raw Materials
# Prioritisation methodology

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Sub-criteria</th>
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<tbody>
<tr>
<td>Economic</td>
<td>Global market share</td>
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<td>Jobs involved in the EU (excluding indirect jobs)</td>
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<tr>
<td>Availability</td>
<td>Amount of CRMs involved</td>
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<td>Expected future market development</td>
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<td></td>
<td>CRM function</td>
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<tr>
<td></td>
<td>Availability and status of substitutes</td>
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<tr>
<td>Strategic Relevance</td>
<td>Associated to specific EU policies</td>
</tr>
</tbody>
</table>
Prioritisation of roadmap themes

1. Motors and drives
2. High value alloys
3. PCBs and electronics
4. Batteries and accumulators
5. Photonics & high end optics

In addition, all of these applications rely on complex electronics
Substitution strategies for CRM in priority sectors and applications
To 2030 (by exception to 2050)
Technical and Non-technical barriers
Drivers for substitution

Drivers for material scarcity (economy-wide)

Drivers for innovation in industry

Opportunities from materials research

CRM Roadmaps for substitution
Roadmapping Process

1. Definition of scope (system boundaries)
2. Expert selection
3. On-line survey
4. Vision workshops
5. Expert interviews
6. Public Consultation
Example of Batteries and Accumulators

**Transport** (Electric/Hybrid vehicles, other.)
- **Drivers**: Safety, Cost, Energy density
  - Pb-A (12V)
  - NiMH
  - Li-ion (Co reduced: NMC, LFP...)
  - LMP

**Portable** (Laptops, smartphones, tablets...)
- **Drivers**: Energy density, Safety
  - NiMH
  - Li-ion (Co-based)

**Stationary** (Industrial)
- **Stationary** (Renewable Energy)
  - **Drivers**: Cost (lifetime), Safety
  - Pb-A
  - NiCd
  - NiMH
  - NiZn
  - Li-ion
  - Power-to-Gas
  - NaS / ZEBRA
  - Pb-A (Sb-free)
  - Redox
  - NiZn
  - Na-ion
  - Li-ion (no-Co)

2020-2025
- PEMFC
- Li-S
- NiZn
- Metal-air
- Na-ion, Mg-ion
- Solid-State

2025-2030
- Metal-air
- Solid-State

**CRM_InnoNet**
Substitution of Critical Raw Materials
Public Consultation

http://www.criticalrawmaterials.eu/consultation/

CRM_InnoNet Roadmaps for Substitution of Critical Raw Materials

The overall aim of CRM_InnoNet is to create an integrated community that will drive innovation in the field of critical raw material substitution for the benefit of EU industry. Part of the activities to achieve this aim has focused on the elaboration of roadmaps to explore pathways for future technology development in priority applications for the energy, transport and ICT sectors, which are of considerable importance to the EU economy. Using a transparent and defendable methodology developed for this purpose CRM_InnoNet evaluated key applications in these three sectors against the key criteria of economic importance, risk for raw materials availability and strategic relevance of the application. This prioritisation exercise identified the five priority applications most likely to be under threat from CRM related supply bottlenecks as:

- Permanent magnet based applications such as Electric Motors and Drives
- Batteries and Accumulators
- High-value Alloys
- Photonics, including High-end Optics
- Printed Circuit Boards and Electronic Components

YOUR FEEDBACK: Public Consultation

Roadmaps for the five priority applications have been developed by the CRM_InnoNet Consortium and in consultation with external experts capturing options and timelines for substituting critical raw materials up to the year 2030.

We now invite your feedback on the Research and Innovation Roadmaps as final validation stage before publication for the themes ELECTRIC MOTORS & DRIVES, BATTERIES & ACCUMULATORS and HIGH VALUE ALLOYS.

Online Roadmap Consultation Survey

Roadmap Priority Theme: Electric Motors and Drives

Welcome to the CRM_InnoNet Roadmap Online Consultation

Please complete this survey to feedback your comments on the draft CRM Substitution Roadmap for Electric Motors and Drives as applications based on permanent magnets. Alternatively you may download the survey via the link provided above and email the filled-in document to criticalrawmaterials@ktm-uk.org.

This survey will close on Friday, 27th February 2015 (at midnight).

By clicking on the Next button below you will enter the survey. Note there are 4 pages of questions to complete as follows:

Confidentiality and Disclosure of Personal Details
- Personal Details
- 6 Roadmap specific questions
- 5 Roadmap general questions

Completing all of the questions related to the roadmap is not compulsory and you may choose to provide replies to only those questions you have the most confidence in answering.
- Current Policies
- International learnings
- Success criteria for substitution
- Vision
- Political requirements
Country Profiles
Networking
of the substitution
stakeholder community

Identify the first set of actors

Energy sector

Consolidate with more stakeholders

Threats

Best practices

Coordination

Dissemination

Launch the pole of excellence

Transport sector

Other sectors

EC

RTOs

Industry

Electronic sector

Innovation

Networking

Standarization

Breakthrough

Requirements

Academia

CRM_InnoNet
Substitution of Critical Raw Materials
Innovation Network

- > 800 subscribers
- > 400 organisations
- > 25 countries

Networking of the substitution stakeholder community

SWOT Analysis:
- Strengths:
  - Platforms for gathering the community across the value chain
  - Focus on substitution itself as compared to other pathways (e.g., recycling, mining, etc.)
- Opportunities:
  - Maturity assessment of innovation based on contribution of different actors
  - Advantage of existing momentum in EU for raw materials
- Weaknesses:
  - Existence of already too many innovation networks (risk of “me too” approach)
  - Time and dedication of community of interested actors
- Threats/External:
  - Network management too time-consuming
  - “EU substitution community” not reaching critical mass
Stakeholder Engagement

• Input into survey on network continuation

• Respond to roadmap consultation – 27th February 2015

• Sign up for project newsletter

• Attend Final Project Conference, tbc

• Follow us on Twitter: @CRM_InnoNet

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