Introduction

**CRM_InnoNet, substitution of Critical Raw Materials** is a Coordination and Support Action (CSA), funded by the European Commission’s (EC) 7th Framework Programme. The project started in November 2012 with the objective of creating an integrated community that could drive innovation in the field of Critical Raw Materials (CRM) **Substitution**: the CRM-Innovation Network. An assessment of the 14 CRM from the EU 2010 list and their substitutability in three selected sectors and applications - Energy, Transport, and ICT and Electronics - have been the main objectives of the project.

In achieving this goal the project has:

- Developed a **methodology** to establish the criteria for the identification and prioritisation of CRM applications which are at “threat” - (Work Package 2).
- Mapped the **CRM landscape**: an overview of the CRM and related technologies subject to substitution complemented by an analysis of the EU-28 plus other relevant countries’ strategies on Raw Materials with a special focus on substitution - (Work Package 3).
- CRM are important for EU industry, therefore an assessment of which specific CRM applications in the value chains of the selected sectors are likely to face problems and bottlenecks was carried out. An analysis of the current risk provision strategies and opportunities of industries with a projection until 2030 completed this task - (Work Package 4).
- Research & Innovation Roadmaps of CRM substitution strategies in the prioritised applications from the results of the previous activities, enriched with the knowledge of industry experts and their business evolution expectations - (Work Package 5).
- Finally a set of **policy recommendations** have been identified. Taking no action will lead Europe to an even more significant external supply dependence and/ or the loss of certain important industrial activities, while implementing the recommendations will help to address the Raw Materials challenge under an integrated perspective looking at supply issues and other important aspects including Europe’s objectives in energy; sustainable technologies; digital Europe; etc. In addition the recommendations highlight financial aspects, incentives and educational requirements - (Work Package 6).
- To secure the continuity of the identified actions and to link them to other activities related to Substitution of Critical Raw Materials taking place in Europe, the **CRM Innovation Network** has been created, which is intended to grow in expertise and undertake outreach activities - (Work Package 6).
- A wide and comprehensive communication and dissemination strategy has been implemented throughout the project’s life and its activities have been achieved by the following means: a dedicated website, flyers, posters, participation in conferences, analysis reports, exhibitions, video, etc. - (Work Package 7).

Context

Critical raw materials are vital to key European industries such as electronics, aerospace and clean energy, but are often entirely imported from outside Europe.

In 2010, the European Commission published “Critical Raw Materials for Europe”, a report of the Ad-hoc Working Group on defining critical raw materials. The Ad-hoc Working Group was a sub-group of the Raw Materials Supply Group chaired by the European Commission. The original scope of this project was the 14 materials on the 2010 list (see Figure 1), not the 20 currently listed, therefore the work of the project developed regarding mapping end-uses, possible substitutes, technologies and value chains was limited to the materials from the original list. However, the exercise carried out in CRM_InnoNet fits perfectly in the revised list of 2014, since 13 out of the 14, with the exception of Tantalum remain as CRM for Europe. Thus, the substitution mapping work performed within the project remains entirely relevant.

**Figure 1 - 14 Critical Raw Materials**

<table>
<thead>
<tr>
<th>SUBSTANCE for SUBSTANCE</th>
<th>SERVICE for PRODUCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROCESS for PROCESS</td>
<td>NEW TECHNOLOGY for SUBSTANCE</td>
</tr>
</tbody>
</table>

The increased attention given to substitution is strongly related to concerns about the steady and secure supply of Critical Raw Materials for the European industry; substitution is expected to play a strategic role in Europe’s long term policies in areas such as energy technologies. There are many technological sectors that are potentially threatened by supply disruptions and solutions may be found by substituting vital functions through innovative materials, components, products, processes or services.
**Selected applications**

CRM_InnoNet explored where the strategy of substitution has the best economic and technological potential for European industry. Following the prioritisation analysis the following application areas were selected:

1. Motors and drives
2. High value alloys
3. Printed Circuit Boards (PCBs) and electronics
4. Batteries and accumulators
5. Photonics and high end optics

**Materials profiles: applications versus substitutability**

In order to understand the opportunities and challenges presented by CRM and the areas where substitution could offer a solution, it was important to look at each CRM individually. A summary of the analysis of the end uses of the materials and the current substitution options - where alternatives might be easily developed and when substitution is not an option for the time being - are shown in figure 2.

**Figure 2 - Materials vs applications substitution alternatives**
Country policies on CRM substitution

To fully understand the situation regarding CRM substitution in Europe, the strategies and the relevant research and technology development funding policies of the 28 EU Member States have been analysed. To complete the scenario, a number of additional countries relevant in the field of critical raw materials have been included in the analysis. These are: Brazil, China, Japan, Mexico and the United States.

For more details: see report "Country profiles" at www.criticalrawmaterials.eu

Supply chain analysis methodology

The value chain analysis was performed by examining the CRM related supply chains of each selected key application in each sector using a common methodology.

It focused on the most relevant applications by screening based on the following criteria:

- Exposure to CRM risk
  The use of one or more CRM (EU 2010 list) in the application
- Current economic importance
  Share of EU production of the value consumed or used in Europe
- Share of the application production in the sector.

The actual supply chain analysis consisted of:

- Statistical analysis of European production, import, export and jobs describing the economic relevance of the application.
- Analysis of criticality, strategic relevance and development of vulnerability in the future, based on technical and market reports as well as via interviews with experts.

These supply chain analyses were complemented by industry interviews focusing on current risks and risk provision strategies associated with CRM relevant applications.

The supply chain analysis focused on the following applications:

- Energy sector
  Photovoltaics (Copper-Indium-Gallium-di-Selenide (CIGS)-technology), wind turbines and energy storage (Li-ion and NIMH batteries)
- ICT and electronics sector
  LED lighting, magnetic resonance imaging (MRI), displays and screens, optical fibre, large household appliances (such as washing machines), printed circuit boards (PCB) and electronic components
- Transport sector
  Automobilies, heavy vehicles and commercial aircraft.

For more details: see reports: Value chain analysis for selected applications at www.criticalrawmaterials.eu

Research and Innovation Roadmaps for Substitution of CRM

The roadmaps elaborated in the context of this project focus on five applications, which have been considered to be of strategic importance for the European industry and describe promising pathways for reducing or eliminating reliance on imported CRMs over the next 10 to 15 years.

The horizon for the roadmap exercise was established at the outset of the project at 2030, since in this timescale currently emerging technologies can be taken to commercial maturity.

Figures 3 to 7 summarise the proposed paths for the five selected applications.

Authors: Tecnalia - Fraunhofer ISI

Figure 3 - Motors & Drives

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motors</td>
<td>Direct Drive</td>
<td>Generator and drive train design optimisation</td>
<td>Superconductor technology</td>
<td>SC production optimisation</td>
</tr>
<tr>
<td>Drive</td>
<td>Gearbox</td>
<td>PM Syn/BLDC</td>
<td>PMCD</td>
<td>PMCD</td>
</tr>
<tr>
<td>Train</td>
<td>Hybrid</td>
<td>Induction</td>
<td>Induction</td>
<td>PMCD</td>
</tr>
<tr>
<td>Gearbox</td>
<td>Hybrid</td>
<td>HPMSSR</td>
<td>SR/SSR</td>
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<tr>
<td>Hybrid</td>
<td>PM Syn/BLDC</td>
<td>HPMSSR</td>
<td>HPMSSR</td>
<td>HPMSSR</td>
</tr>
<tr>
<td>Electric</td>
<td>PM Syn/BLDC</td>
<td>Advanced reluctance, low coercivity PM BLDC</td>
<td>Advanced reluctance, low coercivity PM BLDC</td>
<td>Advanced reluctance, low coercivity PM BLDC</td>
</tr>
<tr>
<td>Vehicles</td>
<td>PM Syn/BLDC</td>
<td>New PM motors: hardmagnetic ferrites, Ce-TM</td>
<td>New PM motors: hardmagnetic ferrites, Ce-TM</td>
<td>New PM motors: hardmagnetic ferrites, Ce-TM</td>
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<td>In-wheel motors</td>
<td>In-wheel motors</td>
<td>In-wheel motors</td>
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<td>In-wheel motors</td>
</tr>
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<td>Research and Technology</td>
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<td>General purpose motor design optimisation</td>
<td>General purpose motor design optimisation</td>
<td>General purpose motor design optimisation</td>
</tr>
<tr>
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<td>Standardised PMDC</td>
<td>Standardised PMDC</td>
<td>Standardised PMDC</td>
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<tr>
<td>Funding</td>
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<td>HPMSSR / HPMSSR</td>
<td>HPMSSR / HPMSSR</td>
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<td>programmes</td>
<td>Axial flux</td>
<td>Axial flux</td>
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<tr>
<td>Material search by High Throughput Screening</td>
<td>Completely new designs</td>
<td>Completely new designs</td>
<td>Completely new designs</td>
<td>Completely new designs</td>
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<tr>
<td>Nanocomposites</td>
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<td>Nanostructures</td>
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<tr>
<td>CRM_InnoNet is not aware of a strategy which has CRM substitution as its primary goal. However, in the EU-28 some countries have developed strategic plans that include a substitution element. In contrast to the small number of strategies covering CRM substitution, a number of Research and Technology Development programmes and calls are relevant to the topic throughout Europe.</td>
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<tr>
<td>For more details: see reports: Value chain analysis for selected applications at <a href="http://www.criticalrawmaterials.eu">www.criticalrawmaterials.eu</a></td>
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Key recommendations

How can substitution reduce Europe’s dependency on externally supplied Critical Raw Materials?

The CRM_InnoNet project has developed an assessment and prioritisation model for the substitution of some CRM in specific applications. This analysis revealed that, although often feasible, substitution is rarely considered as an option by industry. In many cases substitution was considered to be a difficult process due to lack of scientific expertise (in material science), market supply uncertainties, and the substantial investments required from companies.

Policy strategy recommendations

The Raw Materials challenge in Europe can only be solved with a strategy that combines the three supply alternatives: Primary, Secondary (recycling) and Substitution, complemented by initiatives to Reduce and Reuse. Future European policy needs:

A harmonised or coordinated strategy on CRM including substitution for EU and its Member States.

To ensure European leadership, coordination of different instruments (the SET plan, Circular Economy, the development of “green technologies”, Digital Europe, etc.) that rely on CRM is needed to ensure the achievement of goals set in and for Europe - renewed industrialisation, competitiveness, and growth.

A more predictable regulatory and economic scenario is needed to build investment confidence and encourage more research & innovation activities.

Industry & Value Chain recommendations

Industry has the following preferences for CRM supply:

1. Primary
2. Recycling
3. Reducing (although this places a limitation on recycling)
4. Reuse (mainly as components not materials)
5. Substitution

Research & innovation recommendations

Support research and innovation in substitution, based on feasibility analysis (materials versus applications) through EU financing mechanisms including Horizon 2020; the SME Instrument; Structural funds; EIB; EIF; Private investment, etc.

Facilitate knowledge transfer and data collection on the state of the art in substitution.

Non-technical recommendations

Regulation and standardisation: harmonisation at EU level will facilitate approval of new substitution solutions (materials; technologies; services).

Financial aspects: more public-private financing initiatives; EIB; private investors supporting substitution projects. Incentives for companies to invest in substitution (such as tax deductions for innovation).

Public procurement: to faster market uptake and support wider implementation.

Skills and education: new education and training programmes should be devised with a focus on applied knowledge: materials for applications; new “reduced CRM” design etc.

Boost international collaboration and exchange of best practices, especially at early stages of development of technologies and strategies.

Substitution means Evolution, this is a fact of history. We have seen how new products, technologies and services have replaced existing ones and brought more comfort to our lives. This trend will continue whether the result of pre-defined global strategies, breakthrough discoveries, or the rejuvenation of a company’s product portfolio to improve their competitiveness and market share.

We just need to make sure it happens in Europe!

Figure 8 - Summary of CRM_InnoNet Project Activities

- Detailed supply chain analyses of 12 applications in the Energy, ICT & Electronics, and Transport sectors likely at risk of CRM related bottlenecks.
- Charted current risk provision strategies and opportunities of industries.
- Set of policy recommendations on which actions to take to fulfil the objectives of the strategies for critical raw material substitution as identified by the project.
- Systematic overview of critical raw materials and the current possibilities for substitution.
- Analysis of EU and national policies that can influence activities in the field of substitution of critical raw materials.
- Developed methodologies to prioritise potential substitution trajectories identified within the project.
- Applied methodology and identified 5 areas of highest priority.
- Developed roadmap which shows options and timelines for substituting critical raw materials up to the year 2030 (by exception up to 2050) in the priority themes of: Batteries & Accumulators, Electric Motors & Drives, High-value Alloys, Photonics & High-end Optics, Printed Circuit Boards & Electronic Components.

Roadmaps, which show options and timelines for substituting critical raw materials up to the year 2030 (by exception up to 2050) in the priority themes of: Batteries & Accumulators, Electric Motors & Drives, High-value Alloys, Photonics & High-end Optics, Printed Circuit Boards & Electronic Components.