

CRM_InnoNet Final Publishable Summary Report

EXECUTIVE SUMMARY

Please provide an executive summary. The length of this part cannot exceed 1 page.

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 8).
- 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).

PROJECT CONTEXT & MAIN OBJECTIVES

Please provide a summary description of the project context and the main objectives. The length of this part cannot exceed 4 pages.

Securing availability and access to critical raw materials constitutes a strategic objective for the EU political and economic agenda. Key EU industrial sectors such as construction, chemicals, automotive, aerospace and machinery provide a total added value of €1,324 billion and 30 million jobs and depend on access to critical raw materials. Rare earth elements are essential to industrial production, particularly for clean energy options such as wind turbines, solar cells, electric vehicles and energy-efficient lighting. The scarcity of critical raw materials, together with their economic importance, makes it necessary to explore new avenues towards substitution in order to reduce the EU's consumption and decrease the relative dependence upon imports.

Recognising the potential problems that resource scarcity poses to EU industry, the European Commission launched the Raw Materials Initiative (RMI) in 2008 and further updated in 2011. This strategy is being implemented under three pillars: 1) Fair and sustainable supply of raw materials from international markets, 2) Fostering sustainable supply with the EU, and 3) Boosting resource efficiency and promoting recycling. Pillar 2 states that Commission's intention to promote research and development in the raw materials value-chain including extraction, processing and substitution.

According to the report of the RMI Ad-hoc Working Group on Defining Critical Raw Materials, ***"Substitution becomes very powerful where a potentially scarce and critical raw material could be substituted by an abundant one or by a new technology or a smarter product approach."***

For each application of a particular raw material a different substitution approach may be required. The RMI - meeting our critical needs for growth and jobs in Europe - recommended the fostering of substitution as a complementary strategy to recycling to ease the critical dependence of the EU on primary raw materials, reduce import dependency, as well as meeting industrial needs for raw materials.

Substitution is the replacement of a substance, process, product or service by another that maintains the same functionality. Substitution should aim to obviate any negative impacts on human health or the environment and improve resource efficiency over the whole life cycle of the replacement. It should also be recognised that substitution will only be successful where the socioeconomic requirements of all the stakeholders can be satisfied.

Some examples of substitution are given below:

- **Substance substituted for substance:** Polyethylene terephthalate (PET) has replaced glass as the material for soft drink containers. This has dramatically reduced the weight of the package and its associated transport emissions.
- **Process substituted for process:** Caustic soda and chlorine were originally produced by electrolysis of brine in Castner-Kellner cells using a mercury cathode. The process has now been superseded by the use of membrane cells, which do not require the use of mercury.
- **Service substituted for product:** Interface used to sell carpet tiles to its customers but subsequently introduced the carpet service concept whereby customers would not buy the tiles but, for an annual fee, would be guaranteed a floor covering of specified quality. In other words the producer is no longer simply selling a product (carpet tiles) but is selling what it does. This change of business model resulted in the company developing more durable and more readily recyclable carpet tiles.

- **Substituting a new technology for a substance:** a different solution or service to provide the same benefits as the chemical entity being replaced, or technology supporting the implementation of one of the other strategies. Examples can be: Platinum for electrode in fuel cells, replaced by Biocatalysts (in microbial fuel cells), Lanthanum & Cerium in NiMH batteries, replaced by Li ion batteries (electric vehicles), Rare Earths in electric and hybrid vehicles, replaced by new hybrid motors “Rare Earths free”, etc.

Substitution of critical raw materials is a significant challenge that requires new scientific insights, new technology development and ultimately new supply chains to be created in order to succeed in making the EU economy more resilient. In Europe, almost 80% of senior executives from global manufacturing companies cite mineral and metals scarcity as a pressing issue and 67% see this evolving into an area of opportunity, including the possibility of adopting alternative approaches or substitutes. In fact, having the ability to substitute technologies for those not requiring the use of critical raw materials is the most frequently cited requirement to mitigate the effects of mineral and metal scarcity. The expertise required to successfully develop substitute technology options and implement these in the market place requires the close cooperation of end users industries, their accompanying value chains and the knowledge base. These relationships transcend national borders and it is thus imperative that the issue is addressed at a European level.

It is important to act now. Major developing and emerging economies which consume raw materials, and especially China and India, have given new strategic direction to their raw materials policies and have taken measures to ensure their own needs for raw materials are met. This could impact European companies’ access to sources of raw materials, particularly in the medium term. In addition, new studies indicate that the demand profiles for raw materials will change fundamentally in the coming decades due to advances in emerging technologies such as sustainable energy solutions, new ICT technologies such as indium containing displays and high speed integrated circuits and fuel cells and batteries for transport applications. Research Councils UK (RCUK) have quantified some of the increases in demand from new technology projected for several strategic metals. For example, demand for gallium in emerging technologies may increase by a factor of more than 20 between 2006 and 2030. For indium, germanium and neodymium, the factors are 8, 8 and 7, respectively, over the same period.

The Critical Raw Materials Innovation Network (CRM_InnoNet) responded directly to the needs contemplated in the EU Raw Materials Initiative and was funded by the Commission’s 7th Framework Programme in 2012 to drive progress in the field of substitution of critical raw materials by proposing future initiatives and actions in the area of substitution of CRMs oriented to increase the coordination and added value of the EU R&D&I in close connection to industrial future needs and commerce and therefore enhancing the competitiveness of the EU economy.

The overall aim of CRM_InnoNet was to create an integrated community that will drive innovation in the field of critical raw material substitution for the benefit of EU industry.

Starting from a list of 14 CRMs as published in “Critical Raw Materials for Europe”, a 2010 report of the Ad-hoc Working Group on Defining Critical Raw Materials, the project set out to:

- Deliver a mapping of on-going initiatives in the field of substitution of critical raw materials at EU level and Member States that to allow for the identification of key champions and synergies. Mapping to comprise both a ‘top down’ sector-based approach to identify potential bottlenecks in the raw materials value chain and a ‘bottom up’ raw materials-based approach, including mapping of on-going initiatives in the field of substitution of critical raw materials at the EU and Member States level.
- Develop a methodology to establish clear criteria for the prioritisation of applications, which are under ‘threat’ and the technological and non-technological needs regarding the substitution of critical raw materials.
- Elaborate a roadmap for the substitution of critical raw materials in coordination and cooperation with all stakeholders across the critical raw materials substitution value chain

while paying close attention to the specificities of critical industrial sectors as well as possible synergies.

- Create one or more Innovation Network(s) in the field of substitution of critical raw materials ensuring the relevance and usefulness of the project results and constituting a dynamic, open and proactive platform for the entire stakeholder community to support and enhance the competitiveness of the EU industry and economy. Perform a feasibility study considering the potential models and routes for this Innovation Network(s) to endure after the project termination and decide upon concrete future actions in this respect.
- Prepare a document containing recommendations, future initiative ideas and suggested actions for policy makers with the widest possible endorsement and consensus of all stakeholders involved.

The CRM_InnoNet consortium comprised recognised and experienced key actors across the value chain of substitution of critical raw materials representing academia, research establishments and industry bodies of relevant sectors ensuring a wide European coverage and high potential to reach and engage other necessary players across the European Research Area.

MAIN RESULTS

Please provide a description of the main S & T results/foregrounds. The length of this part cannot exceed 25 pages.

1. Material-led Mapping and Policy Landscape (WP3)

Two screening efforts – one for technology and one for policy – were conducted within Work Package 3 in order to inform and focus the discussion around attractive substitution opportunities and to provide a current policy frame for the recommendations of the project.

1.1 Material-led mapping

CRM_InnoNet began work as the original list of critical raw materials (CRM) for the EU (Ad-hoc Working Group on defining critical raw materials 2010) was still in place, i.e. before publication of the revised list in 2014 (Ad-hoc Working Group on defining critical raw materials 2014). Therefore, although CRM_InnoNet promotes substitution of critical raw materials in general and is not strictly bound in its networking and outreach efforts to this list, the scope of the specific work within CRM_InnoNet regarding mapping end-uses, possible substitutes, technologies and supply chains was limited in scope to the original list of 14 critical raw materials for the EU. While this represents an unavoidable limitation, the original list of critical raw materials does match well with the revised list, as shown in Figure 1: raw materials in the scope of CRM_InnoNet are all contained in the revised list of critical raw materials for the EU, with the exception of tantalum. Only borates, coking coal, phosphate rock, magnesite, silicon metal and chromium are out of scope. Therefore, the publication of the revised list of critical raw materials for the EU does not diminish the relevance and actuality of the substitution mapping work performed within CRM_InnoNet.

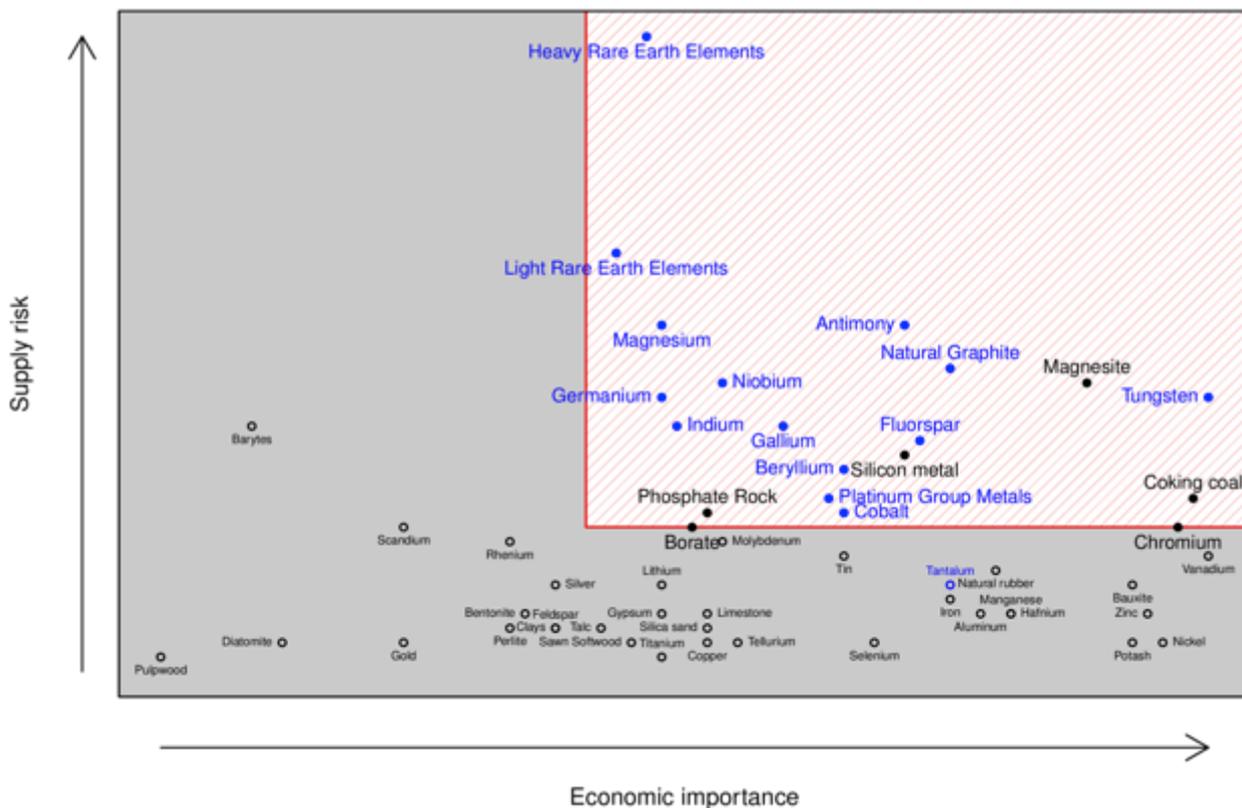


Figure 1: Criticality matrix for the EU as presented by the Ad-hoc Working Group on defining critical raw materials (2014). Raw materials considered critical in the original criticality exercise (Ad-hoc Working Group on defining critical raw materials 2010) are highlighted in blue.

The mapping work on currently available substitution options was carried out in a manner compatible with the methodology used by the Ad-hoc Working Group on defining critical raw materials (2010). Briefly, the function(s) that each raw material fulfills within each of its major fields of application were examined and the current availability of substitute materials and/or technologies was assessed. This assessment, which was inherently qualitative and includes considerations such as relative performance, price and availability of the substitute, was then translated into a common scale, ranging from “easily and completely substitutable at no additional cost” to “not substitutable”. A detailed report for each of the 14 critical raw materials considered was provided in D3.3: Critical Raw Materials Substitution Profiles (www.criticalrawmaterials.eu/documents). Figure 2 provides an aggregated view of these results, with the substitutability assessment coded as colours (green to red) for ease of visualisation.



Figure 2: Materials vs applications substitution alternatives

Inspection of Figure 2 reveals that the 14 raw materials in focus are largely not substitutable without incurring higher costs or loss of performance. The only exception to this is tantalum, which is no longer considered critical in the revised list of critical raw materials for the EU. Therefore, it appears fair to state that there remain ample opportunities for new technologies having competitive performance and price coupled to a strategic advantage in terms of the raw materials required.

In many cases, substitution opportunities are within the ICT, transport and energy sectors (examined in detail in Work Package 4), as seen in Figure 3. However, there are several fields of application that fall outside of the priority sectors considered within CRM_InnoNet and which appear deserving of more in-depth analysis in the future. This includes applications in mechanical engineering (beryllium for mechanical equipment, cobalt for hard metals and tungsten for cemented

carbides), in metallurgy (fluorspar for aluminium production and natural graphite for foundries and crucibles) and in the chemical industry (fluorspar as only significant source for hydrofluoric acid, rare earth catalysts in petroleum refining). Incidentally, these three sectors are three of the largest “megasectors” in the recent criticality study for the EU (Oakdene Hollins, Fraunhofer ISI 2013).

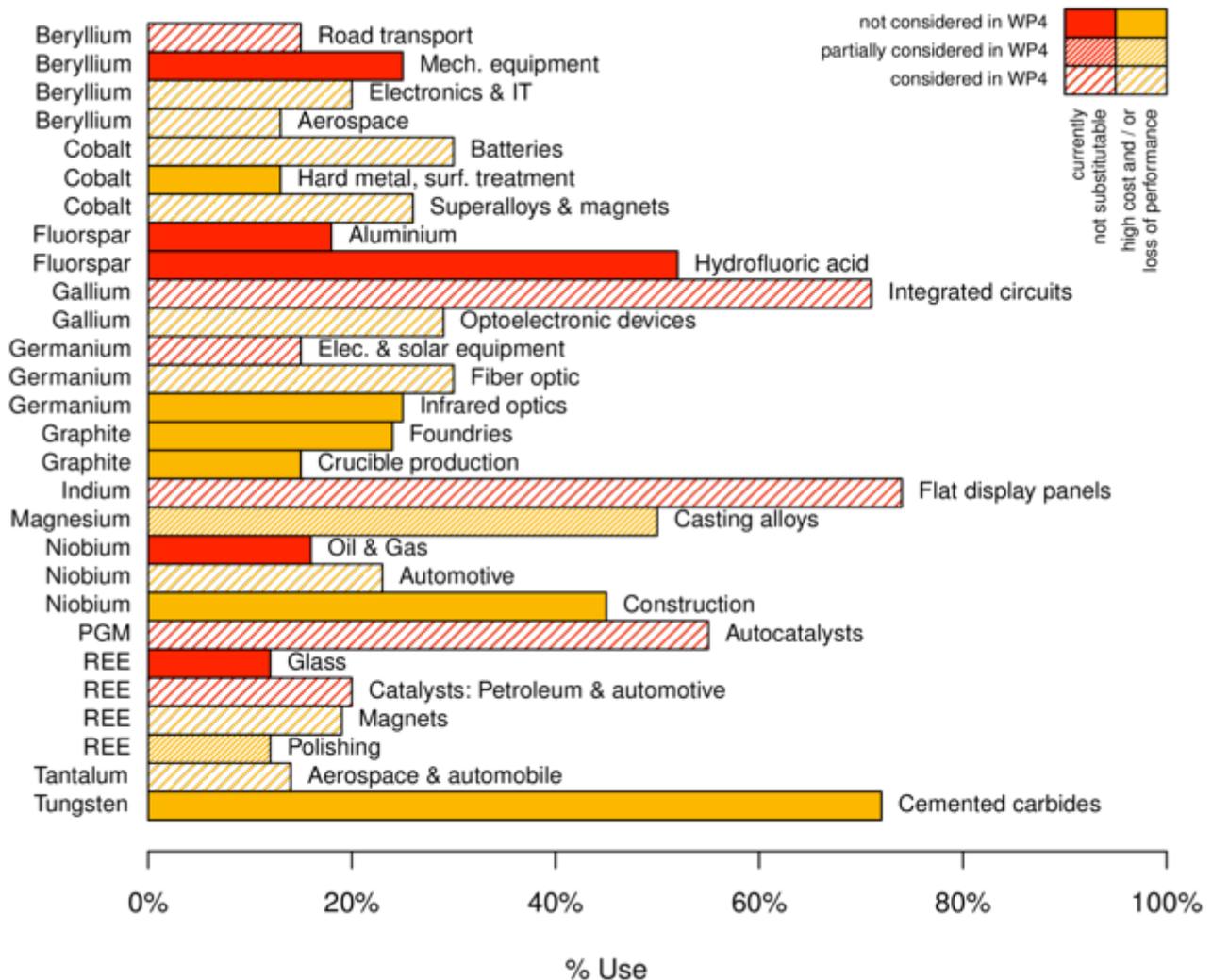


Figure 3: Areas of application of the raw materials examined for which there are currently no acceptable substitution options. The colour scale is the same as in Figure 2 and the shading relates to the degree to which the individual areas are covered by the more detailed work (centred on value chains) carried out in Work Package 4.

1.2 Country policies on CRM substitution

The CRM_InnoNet Consortium also reviewed national and local strategies as well as RTD (research and technology development) funding policies, which target CRM substitution in the Member States and a selected number of additional countries (Brazil, China, Japan, Mexico and the United States). In addition, other instruments that might be used to support CRM substitution such as tax exemptions or public procurement policies were surveyed. Finally, it was analyzed whether and, if so, which institutions are in charge of tracking and helping to address CRM scarcity. A full report of this mapping exercise is provided in D3.2: “Critical Raw Materials Substitution Policies - Country Profiles” (www.criticalrawmaterials.eu/documents).

The review of potentially relevant strategies revealed a broad range of intentions: from mainly environmentally motivated sustainable development strategies, over strategies that are more motivated economically such as mineral and raw material strategies and strategies related to the green economy, to strategies focusing on particular regions, which embody CRM reserves, such as arctic strategies.

1.2.1 CRM strategies

CRM_InnoNet is not aware of a strategy, which has CRM substitution as its primary goal. However, a few countries have issued strategies that put a high focus on CRM. Among the EU Member States, France has issued a strategic metals plan (European Environmental Agency 2011) and Germany issued its R&D strategy “Raw materials of strategic economic importance for high-tech made in Germany” (Bundesministerium für Bildung und Forschung (BMBF) 2012). Both strategies cover CRM substitution. Moreover, the German (Bundesministerium für Wirtschaft und Technologie (BMWi) 2010) and Dutch (The Dutch National Government 2011) raw materials strategies as well as the British Resource Security Action Plan (Department for Environment, Food and Rural Affairs 2012) also cover CRM substitution. From these strategies it seems that CRM substitution is primarily economically and not environmentally motivated.

The policy mapping reveals that a number of the reviewed strategies—in particular general sustainable development strategies—date back to a time before the discussion on CRM. Additionally, it is observed that CRM are indeed covered in a broad range of strategies, however, the focus is often different from substitution. In the countries which are in possession of CRM reserves, the focus is often rather on developing and ensuring more sustainable—environmental as well as social—mining conditions.

Not surprisingly, the extent to which CRM substitution is reflected in countries’ strategies reflects to a large extent the degree of the countries’ CRM dependence. The Industries’ CRM dependence is determined by two factors: first, the relative importance of a manufacturing or high-tech industry and second the availability of raw materials. Since recycling represents, if at all, a minor source for critical raw materials, raw material availability is determined by the countries’ primary material reserves. Figure 4 illustrates this relation. Countries which appear to be less dependent, either because of domestic reserves or because of low industry dependence, often do not target CRM substitution in their strategies. Figure 5 shows the relation between the countries’ industry- and raw material supply structure and the presence of specific strategies and policies.

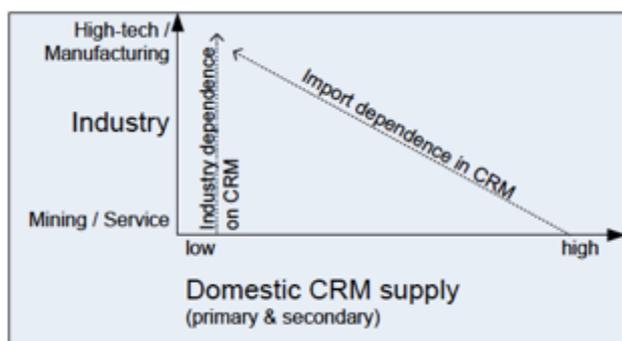


Figure 4: Industry and import dependence in relation to the local industry- and raw material supply-structure

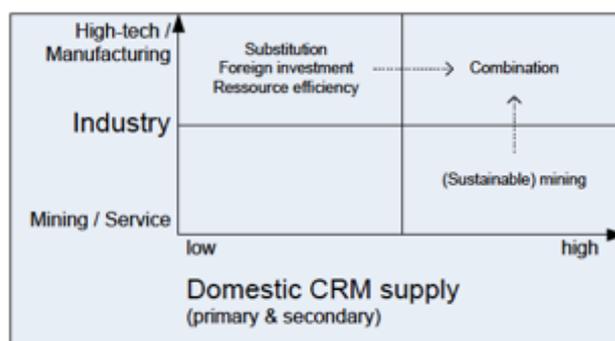


Figure 5: Thematic strategies and policies in relation to the local industry- and raw material supply-structure

Finally, some interviewees indicated that a number of countries are currently developing raw material or CRM strategies. However, in general, it is not possible to give an outlook on what type of strategy are to be expected and what the role of CRM substitution will be.

1.2.2 Research and technology development programs / calls on CRM substitution

In contrast to the small number of strategies covering CRM substitution, a number of RTD programmes and calls are relevant to the topic. In this study the analysis of RTD policies is limited to the analysis of calls and programs. Many more individual researchers as well as research groups work on very particular CRM substitution endeavours at universities and research institutions across the Member States. Their funding stems from general research funding, through EU-wide programmes or through targeted calls. Information on these are only included in some country profiles.

A number of member states host programmes which explicitly mention CRM substitution. One of these calls is in the context of the ERA-NET ERA-MIN network. The second joint call of this network targeted CRM substitution in addition to primary and secondary sources of raw materials. Member States which contributed to the funding of this call were: Finland, France, Hungary, Poland, Portugal, Romania, Spain, Sweden and Turkey (ERA-MIN 2014). None of the funded projects, however, targeted at CRM substitution as was indicated in the CRM_InnoNet policy workshop.

Examples of programmes that can be directly related to CRM substitution are listed in Table 1.

Moreover, in the course analyzing the countries' policies it was recognized that CRM substitution RTD can often be subsumed under material science research calls. Finally, most of the EU Member States issue general RTD funds in which the topics are defined bottom-up by the researchers. Consequently, these might also be used for research on CRM substitution but could not be individually identified.

Table 1: Research and innovation programmes covering (also) CRM substitution.

Country	Institution	Programme	Source
Austria	FFG	Production of the future	Die Österreichische Forschungsförderungsgesellschaft 2014
Finland	Academy of Finland	Mineral resources and materials substitution	Academy of Finland 2014
	TEKES	Functional materials programme	Tekes 2014
France & Germany	French National Research Agency & German BMBF	MatetPro (for France), in Germany included in "Wirtschaftsstrategische Rohstoffe für den Hightech-Standort Deutschland"	Bundesministerium für Bildung und Forschung (BMBF) 2014; L'Agence nationale de la recherche 2013
Germany	BMBF	MatRessource in the Framework program "Material innovations for industry and society" (WING)	Bundesministerium für Bildung und Forschung (BMBF) 2013
Netherlands	NWO	Materials-theme in the NOW-strategy	NWO 2010
UK	EPSRC	Materials Substitution for Safety, Security and Sustainability	EPSRC 2013

1.2.3 Other instruments

The analysis in CRM_InnoNet revealed no other instruments being used to support CRM substitution beyond RTD funding. There is, for example, evidence for public procurement plans which aim at a more sustainable procurement, however, these do not mention CRM substitution. Also no specific tax exemption plans which are associated with RTD into CRM substitution could be observed. However, there are examples of general RTD tax exemptions, such as in Austria (Unternehmensservice Portal der österreichischen Bundesregierung 2014).

Examples of associations that were established as a response to national strategies dealing with ensuring raw materials supply, and also the supply of CRM, are the French COMES (Comité pour les métaux stratégiques (Comes) 2013) and the German DERA (Deutsche Rohstoffagentur 2013).

1.2.4 International benchmarks

The patterns observable in the non-European countries mirror the earlier observations for the EU Member States: resource-rich countries focus rather on mining and exploration while countries in which resource security concerns dominate tend to focus on ensuring their supplies. Substitution presents one strategy that can be used to support the latter goal. Among the analyzed countries, the efforts on CRM substitution are highest in Japan and the USA. In Japan, among others, the Ministry of Economy, Trade and Industry issued strategies which covered CRM substitution. In their 2010 document, substitution presents one of five pillars to ensure material security. Moreover, Japan is very active in research on CRM substitution. Some of these research projects are being conducted with European cooperation. While the United States has some CRM reserves, the country does not appear to be mining-guided. The Department of Energy issued a Critical Materials Strategy (U.S: Department of Energy 2010). Also here, CRM substitution is targeted in RTD programs. China, on the other hand, is well-known for being resource-rich and for dominating supply (and for some products even supply-chains) of a number of materials that are considered critical. Finally, both Mexico and Brazil possess CRM reserves and the focus is on their sustainable mining while also, for example, preserving national heritage.

The full results of the material-led and country policy mapping are published in the following two reports:

L. Tercero Espinoza, T. Hummen, A. Brunot, A. Hovestad, I. Peña Garay, D. Velte, L. Smuk, J. Todorovic, C. van der Eijk, C. Joce, Deliverable report D3.3 “Raw Material Profiles”, <http://www.criticalrawmaterials.eu/documents/key-project-reports/critical-raw-material-substitution-profiles/>

K. Eckartz, C. Sartorius, L. Tercero Espinoza, M^a E. Anta Espada, J. Bachér, A. Bierwirth, E. Bouyer, A. Brunot, J. Etxaniz, N. Fernqvist, G. Garcia, D. Gardner, C. Gonzalez, P. Holgersson, O. Karvan, E. Lindahl, A. Lopez, P. Menger, A. Morales Perez, F. Norefjäll, N. Olivieri, E. Rietveld, B. Serrano, M. Thomtén, C. van der Eijk, Deliverable report D3.2 “Country Profiles”, <http://www.criticalrawmaterials.eu/documents/key-project-reports/critical-raw-materials-substitution-policies-country-profiles/>

2. Supply Chain Analysis (WP4)

CRM_InnoNet analysed applications across the energy, ICT & electronics, and transport sectors to indicate which applications could be under threat from CRM related bottlenecks and which future opportunities for industries are related to these applications. Following initial screening the following 12 applications were analysed in detail:

- 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 represented by washing machines as well as printed circuit boards (PCB) and electronic components
- Transport sector: Automobiles, heavy vehicles and commercial aeroplanes.

Detailed supply chain analyses were carried out for these 12 applications based on three key criteria:

- Exposure to CRM risk: The use of one or more CRM(s) 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 economical relevance of the application
- Analysis of criticality, strategic relevance and development of vulnerability in future, based on technical and market reports as well as interviews with experts.

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

2.1 Supply Chain Analysis - Results

In summary the analyses revealed the applications differ considerably in number of CRM containing components and complexity of their value chains. The analysis further showed that European manufacturing of the selected key applications is focused especially on end products. With exception of CIGS photovoltaics technology and manufacture of Li-ion batteries, the EU occupies a good position in global production with one or more EU companies in the top ten and significant number of jobs in Europe linked to end product manufacturing. There are also possibilities for future growth, because market reports predict that the demand of almost all of the applications will rise significantly by the year 2020. The only exception being NiMH batteries.

In some applications, including all three transport applications, wind energy, MRI industry and selected electronic components of PCBs, significant component production can also be found in Europe. Several of the end products are, however, dependent on essential CRM containing components manufactured outside of Europe.

The key results of vulnerability assessment of the applications can be summarised as follows:

Energy applications: Exposure of the EU wind power industry to potential CRM issues is significant. The availability of permanent magnets may form a bottleneck for direct drive wind power manufacturers due to the growth of global demand of permanent magnets and concentration of their production in China and US. Battery technology may also be at risk although the current production in Europe is limited. The Li-ion technology for transportation is a growing sector, and due to the active research it can be an opportunity for European industry. The EU CIGS PV does not seem to represent a high risk, because the recent restructuring of the EU industry has significantly decreased the EU exposure on this technology.

The transport applications are dependent on several types of components containing CRMs, such as electric motors containing permanent magnets, electronic control units, and CRM containing alloys. The availability of catalytic converters may form a bottleneck for the European automobile and heavy vehicle manufacturers. The European aviation sector does not seem to be very

vulnerable, although disruptions in the availability of Be could cause problems for the industry. Also CRM containing alloys are important for safety reasons. In addition, carbon fibres and titanium are considered critical by the industry, although they are not on the EU list of CRMs.

ICT and electronics applications: Nearly all ICT and electronics applications are exposed to CRM issues through the use of electronic components. Electronic components are dependent on several CRMs with no current substitution options. LED lighting applications, and especially SMEs producing them, may be vulnerable in case of supply shortages of LED dies. The expected very high market growth of LED lighting and manufacture of dies outside of Europe could induce availability problems. About 30% of global germanium is consumed in the production of optical fibre. With no commercial substitution option viable, Ge scarcity may form a bottleneck for increasing production. MRI (magnetic resonance imaging) is dependent on Nb containing superconducting magnets as well as Be and Ho. Europe is strong both in application and superconducting magnet production, and the sector does not seem to be very vulnerable.

The results of the supply chain analyses are presented in more detail in the following three reports:

Brunot, A., Charreyron, V., Chung, C., Mitrofan, L. & Rietveld, E. 2013. Internal report summarising the results of energy sector analysis. CRM_InnoNet Deliverable report D4.1, <http://www.criticalrawmaterials.eu/documents/project-dissemination-downloads/report-critical-raw-material-supply-chain-analysis-for-the-energy-sector/>

Bacher, J., Punkkinen, H., Mroueh, U-M. & Rietveld, E. 2013. Internal report summarising the results of ICT sector analysis. CRM_InnoNet Deliverable report D4.2.

[Final Publishable Summary Report.docx](http://www.criticalrawmaterials.eu/documents/key-project-reports/report-critical-raw-material-supply-chain-analysis-for-the-ICT-sector/)<http://www.criticalrawmaterials.eu/documents/key-project-reports/report-critical-raw-material-supply-chain-analysis-for-the-ICT-sector/>

Bolin, L., Stahl, S. & Rietveld, E. 2014. Internal report summarising the results of transport sector analysis. CRM_InnoNet Deliverable report D4.2.

<http://www.criticalrawmaterials.eu/documents/key-project-reports/report-critical-raw-material-supply-chain-analysis-for-the-transport-sector/>

2.2 Industry and CRM related risk provision strategies

CRM_InnoNet conducted semi-structured expert interviews with nine industrial companies from different countries to assess the industrial perspective of current and anticipated future risks associated with critical raw material dependent applications as well as current risk provision strategies.

From the industry point of view substitution was seen as one of the potential risk provision strategies amongst other examples of risk management measures (Figure 6).

The companies emphasised that solutions to substitution need to be considered from a functional perspective. Instead of substituting single material, the approach may be to replace the application or a component containing CRMs. In most cases the whole process or system needs to be reconfigured, which makes substitution a demanding task. Therefore substitution projects should be initiated based on a thorough business impact analysis, which is a process that takes several years. One of the challenges is that during this period the criticality of the materials may change, e.g. because new technologies are developed or new resources found. In some industries, such as aviation and automobile industry the materials can be changed only after a long and demanding material qualification process.

Although it seemed that most of the companies did not rank the CRM issue as having the highest relevance, it was noted that a proactive approach to substitution gives companies greater flexibility before legislation forces action – awareness therefore needs to be raised.

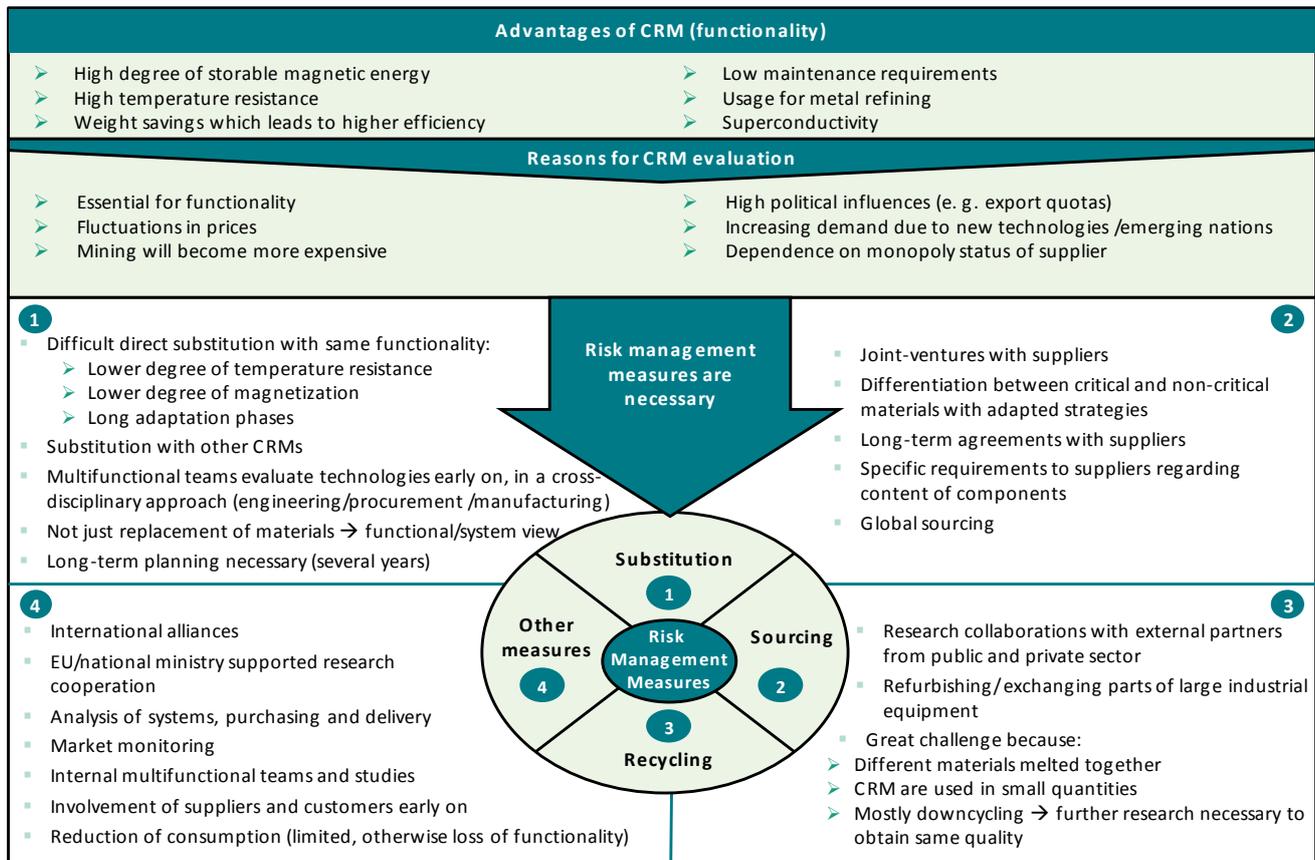


Figure 6: Main outcomes of the expert interviews

3. Prioritisation of applications under threat (WP2)

CRM_InnoNet explored where the strategy of substitution has the best economic and technological potential for European industry. For this purpose a transparent and defensible methodology for prioritisation of applications under threat was developed.

Drawing on the material-led mapping (WP3) and the supply chain analyses (WP4) applications were evaluated with this methodology taking not only supply risk into account but also the following aspects:

- Economic Importance, which measured the value of the application for European industries (supply chain approach (global market share) and the jobs involved in Europe (excluding indirect jobs).
- Risk for Raw Materials Availability summing up several factors, which contribute to potential supply risks and difficulties accessing certain raw materials markets: amount of CRM involved, expected future market development, CRM function, availability and status of substitutes.
- Strategic Relevance, which is associated with EU priorities and strategic targets for the development of specific applications.

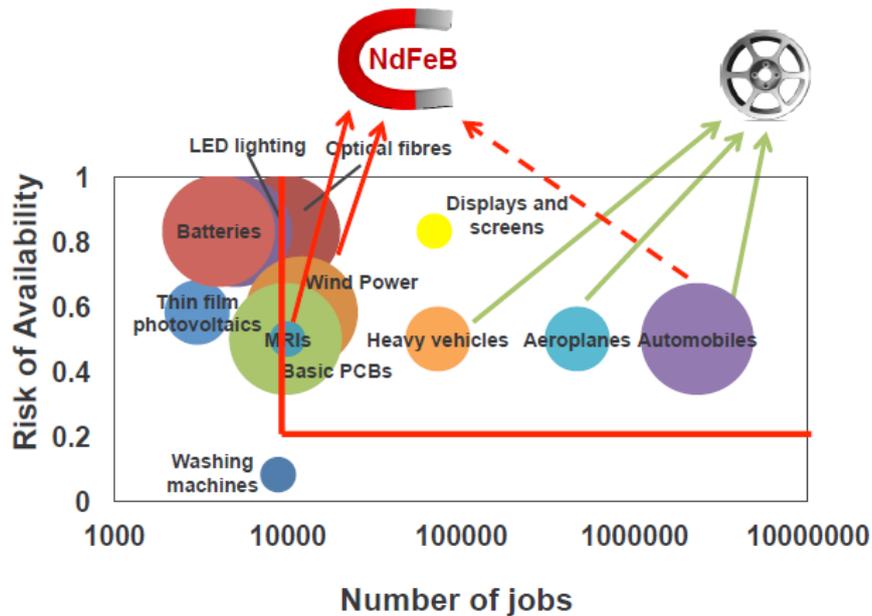


Figure 7: Prioritisation scheme

Five high-priority applications were identified by the prioritisation exercise:

1. Batteries and Accumulators (relevant for mobility, portable solutions and the future energy mix)
2. Electric Motors & Drives (permanent magnet based applications)
3. High-value Alloys (for the metallurgical sector)
4. Photonics & High-end Optics (emerging technologies with special strategic importance for Europe)
5. Printed Circuit Boards (PCBs) and Electronic Components (as key applications for the electronics industry)

A related set of criteria was identified for the prioritisation of substitution technologies and a series of permanent-magnet based technologies was evaluated to validate the methodology.

4. Research and Innovation Roadmaps for Substitution of CRMs (WP5)

The roadmaps elaborated in the context of this project focus on five priority themes, which have been considered to be of strategic importance for the European industry:

- Batteries & Accumulators
- Electric Motors & Drives
- High-value Alloys
- Photonics & High-end Optics
- Printed Circuit Boards & Electronic Components

The roadmaps summarise insights gained on substitution options, as well as the barriers and gaps encountered and describe promising pathways for reducing or eliminating CRMs over the next 10 to 15 years (in some cases up to 2050). To define the substitution priorities and future trends affecting material demand in the five themes, data was gathered through extensive expert consultation as

well as reviews of current and potential future emerging technologies. The full roadmap report available from the project website (www.criticalrawmaterials.eu/documents) entails:

- The approach and methodology applied
- A comparative interpretation of the drivers for material substitution for each priority sector, as well as the most promising substitution pathways
- A detailed description of the five roadmaps
- A summary of the substitution potential in each field

The following sections provide a short summary of the each priority theme roadmap.

4.1 Batteries & Accumulators

Energy storage, and thus Batteries and Accumulators, is considered by Europe as Strategic Energy Technologies (SET-Plan) and represents today a significant economic sector. Its strategic nature relates in particular to the short and medium-term potential of electric and hybrid transportation, and its role as a future enabler for renewable energy penetration in the electricity mix.

However, today's key storage technologies rely on Critical Raw Materials (CRMs). Some material dependence like NiMH (Rare Earths) or Lead-Acid batteries (Antimony) should not be problematic according to the developed roadmap: The NiMH market is seen as decreasing in the medium term, and participation of Lead-Acid technology in the growing applications of energy storage is deemed limited to antimony-free designs (valve-regulated batteries for stationary storage). Current Lead-Acid battery uses like 12V automotive batteries are likely to continue, but are already well addressed today in terms of collection and recycling, mitigating the material risk. Li-ion technology on the other hand is considered as the key technology today for the majority of short, medium and possibly long term applications and suffers from historical dependence on the CRMs Cobalt and Natural Graphite for the electrodes, and Fluoride for the electrolyte. Concerns also exist in the industry on whether Lithium itself could be considered a CRM, due to a high geographic and corporate concentration of production in South-America.

In practice, numerous technologies/chemistries co-exist today even within the Li-ion family, with differences in material compositions. Due to huge future market potentials, technology developments are very active and lead to a high diversity of battery chemistries and solutions available today. This is also stimulated by the different markets addressed, each with its specificities: the main ones being transportation (electric/hybrid vehicles), portable electronics, and stationary storage. New generations of batteries are also actively investigated, which creates a rich panel of potential CRM-reduced or CRM-free options for the medium-term future, even though these may also have an influence on costs or performances.

With its short-term potential uptake, electric transportation is currently driving technology developments of batteries, with a major focus on security and cost, and to some extent energy density (autonomy). Li-ion is seen as dominant in this market for the coming two decades, with performance drivers currently leading to a reduction of the Cobalt use, either partially (e.g. NMC, NCA, etc.) or totally (e.g. LFP). Natural Graphite is not seen as a strong issue (possible substitution by synthetic graphite or new generations of anodes - e.g. silicon, Li-metal), but no specific effort is made to reduce the use of Fluoride. From 2025 on, other non-Li-ion technologies (e.g. Li-S, Metal-air, hydrogen...) may start to be introduced depending on performances and market conditions, broadening the range of possible technology-based substitution.

Portable electronics is already a strong market today, with continuous strong growth. It is mostly driven by an energy density requirement and has a lower sensitivity to costs, which makes it strongly dependant on Cobalt-based Li-ion chemistries. Performance mitigation is seen to be harder on this market, which makes it less favourable to substitution in the short term.

Stationary storage, which is today restricted to specific uses (e.g. industrial sites, hospitals, etc.), is seen as a huge market potential related to the increasing penetration of renewable energy sources (PV and wind energy). There is however a high uncertainty on the actual timing of this market opportunity, the 2030 horizon used in the roadmap being possibly the time for such a market shift.

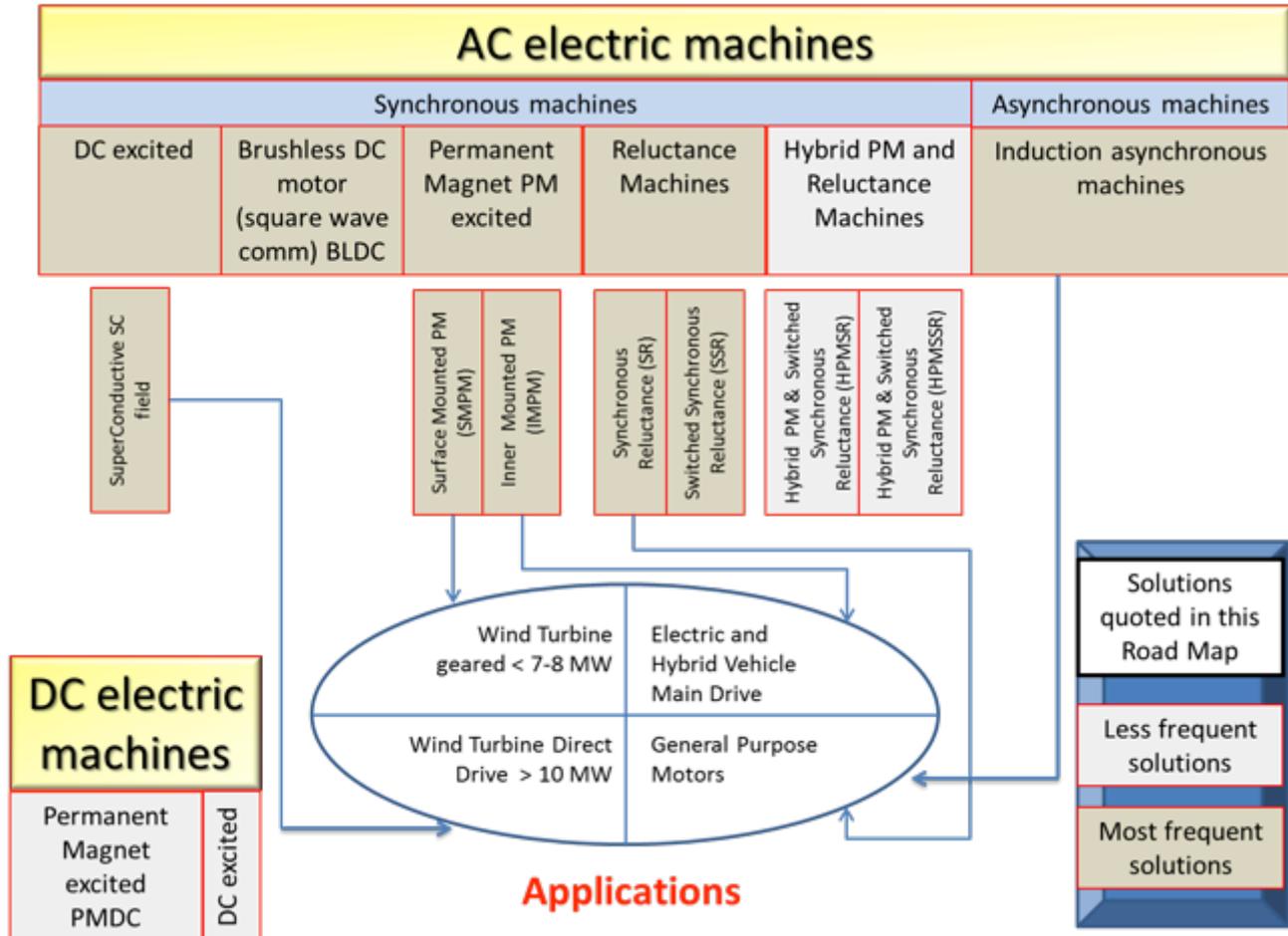


Figure 9: Electric Motors and Drives considered in the CRM_InnoNet substitution roadmap

The roadmap indicates that the main developments determining the need for alternative, REE-free solutions will occur during the time frame covered by the roadmap, i.e. before 2030. At the end of this period, wind producers are supposed to deploy a new generation of large offshore wind turbines (10 MW and beyond), for which REE-free superconducting materials are available. However, during the transition period, 6-8MW direct drive turbines are likely to prevail, which use large quantities of permanent magnets (up to 600kg/MW). Strategies for minimizing PM content and eliminating dysprosium (Dy) are already in place and may help to alleviate the dependence on rare earths. These minimization strategies will be very relevant if the deployment of large off-shore turbines takes longer than expected, due to technical problems, unfavourable trends in the energy market or other societal reasons such as lack of public acceptance.

A key factor on the demand side is electric and hybrid mobility, which has the potential to become the dominant technology for vehicles from 2025 on as a result of much stricter emission standards. The automotive industry is researching a great variety of solutions, which do not require rare earths or work with lower quantities of Neodymium (Nd) and Dy. Alternative technologies are also being developed by smaller innovative companies, specialized in the field of electric and hybrid mobility, which include new drive concepts, such as in-wheel motors. New designs of motor topologies that reduce temperature stress on permanent magnets are currently explored in order to reduce Dysprosium content.

The producers of industrial multi-purpose motors are carefully monitoring the development in the field of electric and hybrid mobility, as the price hikes for permanent magnets in 2008/2009 raised awareness on potential supply problems. Market leaders such as ABB and Hitachi reacted quickly

and now offer a magnet-free synchronous reluctance motor and a rare-earth free permanent magnet synchronous motor, respectively, with high efficiency levels for a wide range of applications. Also smaller motor producers and users are attracted by the idea of a PM-free alternative to reduce dependence on permanent magnets, but face greater difficulties in implementing these solutions. Experts argue, however, that presently available motor designs are close to the maximum efficiency level achievable, so that completely new motor designs need to be implemented by 2030.

HREE- and REE-free permanent magnet candidate materials are currently identified by High Throughput Screening methods. A new generation of nanocomposites and nanostructures could substitute for HREE or REE in permanent magnet materials in the long-term, if substitution pressure remains high. Meanwhile production processes are optimized in the short-term to reduce HREE and REE content of permanent magnet materials.

Finally, it has been observed that technological developments are mainly driven by industry, but research organisations play a leading role in crosscutting solutions, such as the search for new magnet materials and in entirely new design concepts for general purpose motors.

4.3 High-value Alloys

The scope of the roadmap is limited to alloys that contain elements that are on the list of critical raw materials or that need materials from this list to be produced. The prioritized areas are the steel industry (because of the large amounts of materials processed), cutting tools and materials for aerospace turbines; the latter two due to the important role of CRMs in these high performance materials. The time horizon for the roadmap, 2030, is quite narrow, as the development of new, substitute materials and its acceptance in a rather conservative market, such as the aerospace industry, usually takes longer (about 20 years).

In the case of material demand by the automotive industry, a greater use of high-strength steels can be expected, but also of other lightweight materials, such as aluminium or carbon fibres. The use of higher-strength steel in the automotive industry faces certain challenges related to downstream processing of the advanced high strength steels, such as forming of the body, welding and coating. The expert groups identified numerous research initiatives aiming at the substitution of CRMs in high-value alloys and other hard metals (mainly Tungsten, Cobalt, Molybdenum, Magnesium and heavy rare earth elements, but Nickel was also mentioned). Several of the mentioned initiatives aim at accelerating material innovation. Several examples and initiatives in this field were cited, i.e. multi-scale material design, GRANTA material database, Integrated Computational Materials Engineering (ICME), Accelerated Metallurgy (High-throughput materials science), which could eventually give a decisive competitive advantage to European industry.

It is important to take the substitution of materials that are used during production but that are not included in the final product into account. An example from the past is the substitution of hexavalent chromium plating which is toxic. Its use has been restricted due to legislation.

It was also recommended that abandoned alloy designs should be revisited to evaluate their potential for substitution. A strong link was established between substitution, material design and changes to industrial metallurgical processes (castings, coatings and novel concepts, or change of microstructure instead of alloy, i.e. substitution strategy process for substance), as well as the use of alternative reductants to substitute coking coal. The following approaches were highlighted:

- High quality castings to replace CRM containing alloys
- Coatings that reduce the product requirements to the bulk of a product thereby decreasing CRM use
- Electrolytic production of titanium production avoiding Mg use
- Near net shape technologies/additive manufacturing projects
- Low cost solar silicon through metallurgical processes substituting the Siemens process
- Microstructural refinement to improve properties substituting alloy elements

- The use of natural gas as reductant for iron, silicon and manganese as substitute for coking coal coupled with reduction of CO₂ emissions

When it comes to cutting tools, it is difficult to find a substitute for WC-Co. The good wettability between WC and Co is the basis for the good performance. Substituting the binder without substituting the cutting tool or vice versa is therefore difficult. Cobalt is, at this moment, the most critical element for the industry. Some iron-based binders are under development. It should be noted that Cobalt is toxic. A change in legislation will accelerate the pursuit for a Cobalt substitutes. The cermets that have been developed until now are too brittle to substitute today's cutting tools. In order to start using cermets today, a large change in the manufacturing industry is necessary and that is not anticipated. Without an extra-ordinary research effort it will take at least 20 years before proper substitute materials for each hard metal are ready for commercialisation.

When it comes to steels, alloying elements that are on the list of CRMs can be substituted by other alloying elements or by improved microstructural control. Chromium is necessary for stainless steels, but low-alloyed steels with improved corrosion resistant coatings (e.g. galvanization) can substitute stainless steels. Coking coal is on the list of CRMs because of the uncertainty of supply due to flooding of coalmines. Coking coal can partly be substituted by injection of coal during blast furnace operation. This is under development and will be used as much as needed. Moreover natural gas can also be injected during blast furnace operation. The use of natural gas reduces also the CO₂ emissions from the industry but natural gas is, in Europe, much more expensive than coal. The production of iron with natural gas (Direct Reduced Iron) is not expected to increase so much that it will significantly influence the demand for coking coal. More research on substitutes for coking coal can be of benefit for the whole steel industry.

The aerospace industry has a risk aversive culture that makes changes slow and stepwise. The most critical elements for turbine parts are mostly the alloying additions to the Ni-alloys like: Rhenium, Tungsten, Tantalum, Hafnium and Niobium. Rhenium is a scarce material. There is an ongoing development towards the reduction in the use of Rhenium in turbine parts. By using coatings, some of which containing Yttrium oxide and platinum, one can decrease the requirements for the alloy, thereby decreasing the required amount of CRM. When coating is applied, maintenance and recycling are challenging. There is still a lot of development potential in conventional superalloys. At the same time there is research and development within intermetallic, ceramics and CMC. These new materials have shown promising performances, but only in lab-scale/pilot testing. The aerospace industry is a very conservative industry. Therefore it is not expected that these new materials will take the place of superalloys within commercial aviation any time soon. Recent developments in atomistic and other modelling, can accelerate substitution, although thorough testing is always a requirement in the aerospace industry.

4.4 Photonics & High-end Optics

The field of photonics is broad, and developing a roadmap for substitution of CRMs in photonics in a fully homogeneous way is a challenge within the framework of this project. It is highly likely that the work will extend beyond the end of this project. The majority of photonic technologies contain at least one CRM, although the precise number and the importance of the CRM vary significantly from one application to another. This roadmap therefore focuses on the photonic technologies that have been identified as the most critical regarding their use of CRMs and their importance in the global photonics market.

One of the most widespread concerns regarding CRMs in photonics is the indium supply risk and price volatility. Indium is an essential component of ITO (Indium Tin Oxide) coatings used in flat panel displays. Given that this sector (a) accounts for a large share of the total world market for photonics, and (b) at the current rate of ITO consumption the US Geological Survey suggests that Indium will be highly critical[1], this problem could seriously affect the photonics sector. The market is cautiously reacting to this issue by proposing alternatives to ITO based on carbon nanotubes (CNT), conductive polymer films, and copper solutions. CRM_InnoNet highlights the use of fluor tin

oxide (FTO) as an existing and graphene as one of the most promising, research substitution strategies for ITO.

Another important line of substitution strategies for CRMs in photonics is the use of rare earth elements (REEs), Gallium, and Indium in light emitting diodes (LEDs). Here we have to make a distinction between white LEDs used for lighting applications and red, green, and blue LEDs used for flat panel displays. In the case of lighting the increasing market demand for LEDs is being reinforced by the EU policies focused on phasing out of incandescent bulbs and seeking low energy alternatives. Industry supports the selection for existing LEDs, which are highly CRM dependent, is the use of organic LEDs (OLEDs) (except for phosphorescent OLEDs that are also strongly dependent on REEs). But even if OLEDs develop as an excellent candidate to produce eco-friendly CRM-free flexible displays and lighting sources, the current cost and luminous efficacy issues are delaying its commercial deployment and give rise to doubts about OLEDs taking up a significant market share from LEDs by 2030. Another solution driven by the industry is the development of LEDs using quantum dots instead of REEs.

The laser market does not seem to be clearly reacting to the potential price volatility of Yttrium. Some experts believe, and this affects also to other fields of photonics, that the problems with the supply of rare earth elements will not be very critical for laser technologies, due to the small amounts of REE needed. However, in the event that the future means Yttrium shortages or acute price peaks, there are readily available high-power fibre laser solutions that could replace the widely used Nd:YAG laser for industrial applications such as marking and welding, even in some medical applications, such as surgery.

Finally, the photovoltaic (PV) market has also given rise to some concerns regarding the use of CRMs. There are particular PV technologies that use CRMs as their critical active material, amongst them copper indium gallium selenide (CIGS) and single and multi-junction GaAs cells. CIGS technology is one of the established thin film technologies, whose main advantage is that they can be applied on flexible substrates. Multi-junction cells on the other hand are by far the most efficient PV technology, but their cost is also much higher. Thin film amorphous and microcrystalline silicon are not CRM dependent, but currently lag too far behind in conversion efficiencies to constitute a viable alternative for thin film CIGS cells. The market-dominating crystalline Silicon technology is also not CRM dependent, but it cannot be applied on flexible substrates. For the high efficiency sector, there is no other commercial PV technology that matches multi-junction GaAs. There are, however, promising research strategies to improve the efficiency of thin film cells by using photonic crystals or hetero-junction concepts that aim at efficiency values closer to the ones achieved with multi-junction.

The figure below shows the substitutive solutions identified in the roadmap:

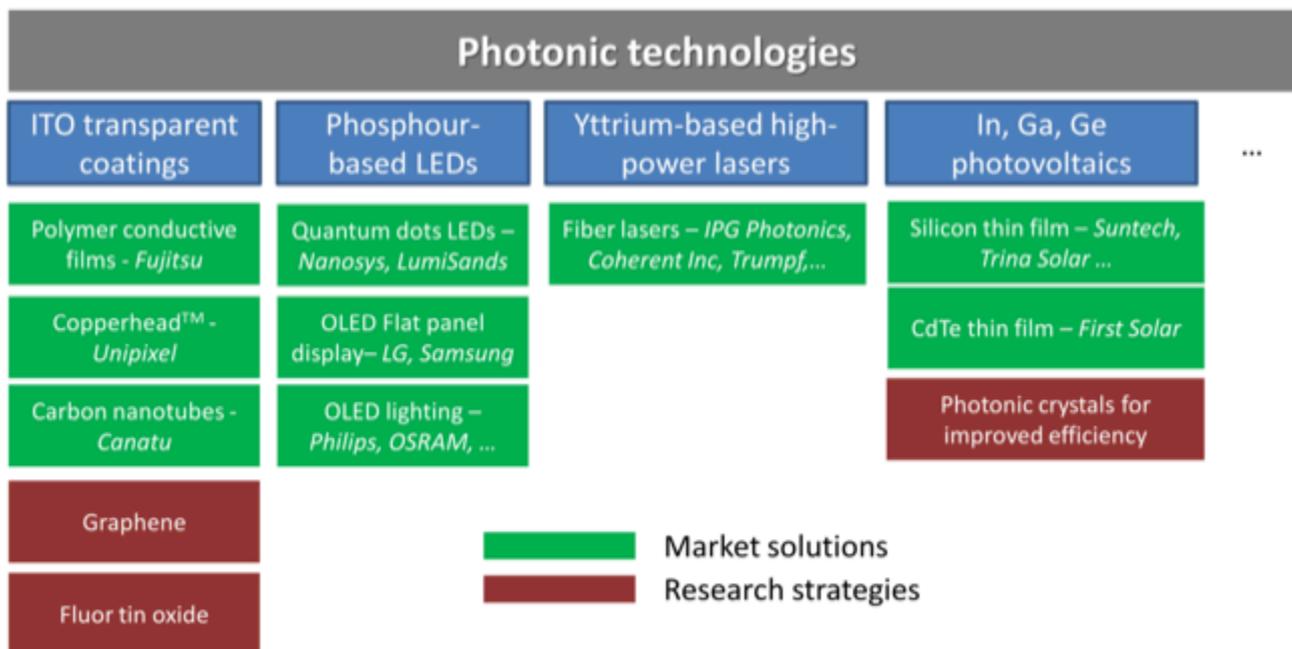


Figure 10: CRM substitution solutions identified for Photonics and High-end Optics

Finally, it has been observed that technological developments are mainly driven by industry, but research organisations can also play a leading role in cross-cutting solutions, such as the search for graphene alternatives to ITO and the use of photonic crystals for improved solar cell efficiency.

References

[1] Note that information provided by Indium Corporation to this Consortium directly shows a much more positive perspective in terms of Indium reserves and potential for more capacity/output increases. However we have to reflect the market trends, and these show a clear concern for Indium price volatility and supply shortage.

[2] See for example IPG Photonics TLR-200 Thulium CW Fiber Laser.

4.5 Printed Circuit Boards & Electronic Components

The European electronic components industry has a significant impact on the EU economy both in production values and in jobs even though the biggest global actors are situated outside Europe. Europe is particularly strong in high performance electronics used in innovative industrial and professional end applications. The application sectors include transport, power, health, security and other industrial. Europe is also well positioned in the R&D of new manufacturing solutions and materials: printed and organic electronics, additive manufacturing/3D printing, nanoelectronics and system integration.

The roadmap considers assembled printed circuit boards (PCBAs) and the electronic components used in the assemblies. The structural and material composition of PCBAs is defined by the performance requirements of the end application, which may be different even in the same kind of applications. Practically all the PCBAs and their components rely on one or more critical raw materials (CRMs), and usually the high performance applications have the highest CRM dependencies.

Supply risks or criticality of raw materials have not been among the main concerns of the sector. The key drivers are the performance requirements as defined by the applications, flexibility, miniaturisation, temperature resistance, short lifecycles of the products and to an extent price. There are, however, some examples where substitution has taken place, such as:

- Replacement of PdAg multilayer ceramic capacitors (MLCCs) by Nickel based MLCCs in most of the applications. PdAg is still used in the high performance applications, especially in aeronautic and military sectors. The main driver for substitution has been the rising Palladium (Pd) price. Wider substitution has been enabled by the development of ceramic materials. Also the consumption of PdAg in conductive tracks of hybrid integrated circuits has been decreased due to the miniaturisation of the circuits.
- Replacement of tantalum (Ta) capacitors by multilayer ceramic capacitors has decreased the consumption of Ta in electronics.
- Substitution of materials prohibited or expected to be prohibited by the legislation. So far the main focus has not been on CRMs, but the phasing out of toxic compounds, such as lead solders. The forward-looking companies of the sector have also started discussions on taking into account the impact of extraction and on conflict-free material sourcing, which could enhance substitution.
- Tablet and mobile phone substitution of PCs has reduced the consumption of Ruthenium (Ru) in electronics. Ru is mainly used in hard discs, which are not needed in mobile devices.

At present the main concern is the use of Gallium (Ga) in PCBAs and electronic components. Due to its unique properties about 60 % of Ga is used in integrated circuits and transistors in mobile devices, WiFi etc. In addition, the efficiency requirements of the power electronics applications have led to the substitution of silicon (Si) with GaN in a part of power electronics. It is expected that the consumption of GaN will grow and be about tenfold by the year 2025. SiC and InP have been studied as potential substitutes for GaAs, but both Si and In are also CRMs. There has been some research on graphene as a substitute for Si and potentially for Ga, but graphene is still in the development stage. Probably it is not suitable for current type of circuits, which means that more fundamental changes in electronics are needed.

Future developments, such as increasing adoption of data centres and growing demand of high performance electronics may induce limited growth of the consumption of platinum (Pt) and Pd. Also beryllium (Be) is a potential concern because of its criticality and toxicity. About 20 % of Be is used in electronics, most usually as BeCu alloy. Potential substitutes include Ni, Si, Sn or Ti. One example of phasing out of beryllium connectors in phones has been presented by Nokia (currently Microsoft). BeCu is still mostly used because of its performance characteristics, but there are possibilities for more extensive substitution in the future.

Substance by substance substitution strategies have in many cases turned out to be poorly suitable for electronic components, because until now the only substitutes with decent performance characteristics have been critical raw materials with similar properties as the original material. Therefore the most probable options for reduction of the consumption of critical raw materials will take advantage of the expected future development of electronics manufacturing and material technologies, such as development of printed electronics, additive manufacturing technologies (3D printing) and nanoelectronics. Instead of trying to find substitutes with similar performance characteristics as the materials in the current electronic components, the new solutions should offer new functionalities required by the future applications. Reduction of consumption of CRMs can be enabled for example by development of organic inks and organic electronic components, 3D printing enabling printing inside the housing replacing printed circuit board and integration of components, such as electronics, sensors and batteries. Also continued miniaturisation of electronics will further reduce the consumption of CRMs.

References

[1] Bulliondesk 2014: <http://www.bulliondesk.com/gold-news/focus-escalating-palladium-costs-sees-drop-use-electronics-production-78835/>

4.6 Conclusions

4.6.1 Drivers for substituting critical materials (cross-analysis of the five roadmaps)

The five priority applications were selected because their future development is highly dependent on the availability of critical materials. Addressing supply and price risks, however, requires a profound change in the companies' innovation strategies, which, in recent years, have tended towards an ever-increasing use of "exotic" materials to achieve improved performance. Performance, expressed as flexibility, miniaturisation, temperature resistance and – important - short lifecycles of products, is especially relevant in the electronics industry, which, for this reason, is even anticipating a greater use of the CRM gallium in future applications. This implies that a substitution strategy aiming at reducing CRM use is contrary to the "natural" innovation trends in these industries and will only be implemented if landscape pressure increases and access to these prime materials is no longer guaranteed.

The situation is similar in photonics, with the slight difference that many of the applications in this field have entered the market quite recently and have not yet reached the maximum production level. The same situation has been observed in the battery market and, in both cases, leads to a situation, in which concerns about CRMs do not rank high on the companies' list of priorities. However, in the most advanced segments of these two markets (LEDs and batteries for transport purposes), the possible need for substituting CRMs is recognized and reflected in the research agendas. Cross-fertilization, i.e. the potential transfer of a substitute solution from one application to another, could become an important element for composing the "reconfiguration pathways" referred to in chapter 3.

Drivers for substitution are much more evident in the case of electric motors and high-value alloys, due to high importance of material cost for these industries and recent experiences with volatile prime material markets. In these industries, the main challenge consists in speeding up innovation processes so that companies can respond in a more flexible way to pressures on the landscape level. The most promising substitution strategies identified in the roadmaps for these sectors are embedded in entirely new designs (motors, batteries for transport) or material combination and compositions (CMCs).

4.6.2 General recommendations (cross-analysis of the five roadmaps)

There are four key issues related to strategies for the substitution of critical materials, which are a common concern for all applications covered in the five roadmaps and therefore need to be addressed at a general level. The cross-sectoral challenges identified in the expert discussions are:

1. Material substitution is presently addressed on the level of individual companies. The EU does not have an economy-wide substitution strategy in place. In relevant reference documents, such as the Roadmap to a Resource Efficient Europe[1], substitution is mentioned alongside mining, reuse, recycling and other strategic actions, but fact is that there is not yet an established industry network pursuing material substitution in response to price increases or supply risks of scarce materials, whereas companies active in the mining and the recycling sector do make their voice heard in related EU initiatives. At first glance, there appear to be conflicts between these multiple strategies, since the recycling business might become less profitable if certain high-value fractions of the waste are eliminated or used in lesser quantities (minimisation of CRM content). Mining companies or suppliers of CRM-based products with a strong market position can also show opposition to research on material substitution as substitution would reduce demand for CRM supply. However, from the policy perspective, these strategies are complementary, because, as shown in the roadmaps, substitution aims at the transformation of markets and products over a period of time, which is long enough for other actors to adapt to changes in the material composition of products.
2. It has been observed that companies first react to pressures on material costs by trying to minimise the content of expensive materials and only consider full substitution and a redesign of a product when minimisation is not feasible or does not solve the problem. A second short-term option available to companies is that of trying to increase the useful life of

a product, which is also beneficial from the EU perspective, as it helps to decrease the overall material demand of the economy, expressed as “material intensity”. This solution, however, only fits with companies, whose business model is at least partially service-oriented or which consider durability to be one of the competitive advantages of their product. As discussed in the roadmaps, this is the case in some sectors, for example battery production for transport, but is not deemed equally relevant in quickly evolving sectors, such as electronics.

3. In the annex of the EU Resource Efficiency Roadmap it is remarked that better foresight is needed to anticipate price hikes for critical materials, which can endanger the profitability of certain sectors of industry. This is an extremely relevant question, since developing new materials and new processes is expensive and companies shy away from investing in R&D when rates of return are highly uncertain. The problem is exacerbated because prices of raw materials are greatly influenced by speculation, which, in turn, is facilitated by monopolies on the supply side and bottlenecks along the value chain, so that price forecasts are characterized by a high level of uncertainty. It is, however, possible to anticipate which materials could become a preferred playing field for speculation by analysing the mentioned bottlenecks, for example the lack of producers of rare earth magnets in the Western countries, along with the elasticity – or lack of elasticity – on the supply side and the overall trend in demand. Part of this analysis has been done by the EU expert group and has been confirmed in earlier work in CRM_InnoNet (WP 3), but was mostly limited to the present situation. Much work is still needed to obtain a clear overview how worldwide developments in all economic sectors combined will shape the future demand for materials, since the roadmaps only cover a limited number of applications, although of high strategic relevance.
4. The expert consultations made clear that a specific, new research field “design for substitution” has to be defined to face the challenge of declining mineral resources. A higher level of cooperation between designers, material scientists and companies – or their associations – is required to deliver innovations in the material field quicker and to accelerate the market uptake of solutions that can help to reduce Europe’s dependence on imported materials and semi-finished products. New testing facilities may be necessary to guarantee that especially SMEs have access to new materials and characterization tools and such facilities should be considered in the work of ESFRI on large research infrastructure.

Finally, one question has been raised during the roadmapping work that cannot be answered by a single project on material scarcity. In many industries, European companies operate at the end of the value chain and import most of their semi-finished products from outside Europe. This implies that some direct substitution measures are beyond the influence of the European producers, unless Europe is able to rebuild its industrial base and to create entirely new material supply chains. Medium and large companies have the option of solving this problem by transferring part of their production in countries with abundant supply of materials, which are also often closer to growing markets. This trend has considerably weakened Europe’s industrial base and increased its dependence on imports. As one expert put it “It’s a problem for Europe as a continent, companies can relocate, and Europe cannot”. But this means that it is of utmost importance to identify those actors, who could be the driving force for large-scale structural change in the European economy. Synthesizing new materials in the lab to reduce dependence on mining in developing countries may well become a cornerstone of Europe’s reindustrialization.

References

[1] COM(2011) 571,

http://ec.europa.eu/environment/resource_efficiency/about/roadmap/index_en.htm

5. Policy Recommendations (WP8)

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

A shortened timeframe to innovation is crucial to increase effectiveness and success rates through: more basic research in materials science; use of modeling and simulation technologies; and closer collaboration between academia and industry. Integration at early stages of development of materials and product design experts. Development of new business models such as leasing, service for product; etc. Investing in substitution is a risky decision for companies in terms of cost, time, safety, etc. To encourage substitution innovation the following factors will have a positive impact: CRM stable market conditions; a harmonised approach within the value chains (awareness); supply/demand evolution.

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-technological 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.

The full policy brief on critical raw material substitution is available on the project website at www.criticalrawmaterials.eu/documents.

6. Innovation Network

CRM_InnoNet was established to create a network to form an integrated community driving innovation in the field of critical raw material substitution for the benefit of EU industry.

Three strategic Innovation Network workshops were organised during the project duration with the intention to create an Innovation Network on substitution, which would provide a platform for stakeholders interaction across the duration of the project and beyond, and favour the exchange of information and dialogues over the substitution of Critical Raw Materials (CRMs) for the benefit of EU industry. The participants in the three strategic Innovation Network workshops and in the other CRM_InnoNet activities, formed the seed of the Innovation Network on substitution of CRMs.

In total the three strategic Innovation Network Workshops on substitution of CRMs gathered more than 350 participants from 210 organisations (Industry, academia, research organisations, associations and also policy makers) and 22 countries. Those workshops provided a platform for information exchange between participants to inform about strategic issues such as:

- How substitution of CRMs is considered in industry
- What are the CRM profiles
- What is the position and importance of the EU industry in value chains of applications in the Energy, ICT and Transport sectors
- The five prioritised applications identified by CRM_InnoNet
- The main current substitution activities at the European level
- The need for an Innovation Network on substitution and what would be its most useful aspects
- The main available mechanisms for engagement on the substitution topic

The workshops provided also the opportunity to gather information from participants for setting up the roadmap of the five prioritised applications.

The main lessons learnt after the organisation of those workshops indicated that:

- 1- The business model of substitution is not trivial and thorough technical and non-technical analysis in each specific case is required by a company to investigate further the possibility to substitute a well-performing critical raw material.
- 2- The research on substitution in Europe exists but is fragmented and had low visibility. 19 projects funded by the European Commission focusing on substitution were identified in addition to CRM_InnoNet and the majority were successfully engaged in the CRM_InnoNet activities. Thus the workshops organised by CRM_InnoNet provided high visibility and an opportunity for those projects to network with each other. The European Commission organised the 1st “cluster meeting” of European projects related to substitution in conjunction with the last strategic workshop of CRM_InnoNet with the intention to continue this initiative in support of greater coherence and exchange between projects.
- 3- A survey conducted with workshop participants showed that the Innovation Network was perceived as value-adding especially with regards to networking and community building. The survey further yielded that the majority of participants would like to see the Innovation Network to continue. However, substitution of CRMs is not yet regarded as topical enough to reach critical mass for financial support by the community that would sustain the Innovation Network activities.
- 4- Several opportunities for stakeholder engagement on the substitution topic are provided by the main EU programmes which are the EIP on Raw Materials and the EIT Raw Materials.

The wide reaching potential of the CRM_InnoNet partners and the extensive dissemination campaigns during the project were essential in gathering a critical mass of stakeholders interested in the substitution topic. However, to keep the momentum going and the stakeholders engaged, significant dissemination and promotion efforts were undertaken (e.g. newsletters, social media feeds, workshops, follow up activities, etc). Since substitution is still a fairly new topic the Innovation Network is not yet at the stage of self-sustainability and activities in the topic will still need strong leadership in the coming years.

A study performed by CRM_InnoNet on the possible mechanisms for the continuation of the Innovation Network on substitution after the end of the CRM_InnoNet project concludes on the most feasible strategy to be followed. The main conclusions indicate that:

- 1- The Innovation Network on substitution of CRMs will remain an open and dynamic network for the coming years. The Innovation Network will encompass interested stakeholders in the substitution topic having different commitment levels according to their interests.
- 2- Several mechanisms have been identified in deliverable report D6.1 to allow the Innovation Network members with different commitment levels to remain engaged in the substitution topic for the coming years. Figure 11 and 12 summarise the identified mechanisms for ensuring the sustainability and endurance of the Innovation Network on substitution of CRMs after the completion of the CRM_InnoNet project.
- 3- The two most likely mechanisms to keep the momentum going are the EIP Raw Materials Commitments and the EIT Raw Materials.
- 4- The CRM_InnoNet website will be maintained until at least 2020. It will continue to provide information on projects and initiatives related to substitution of CRMs.

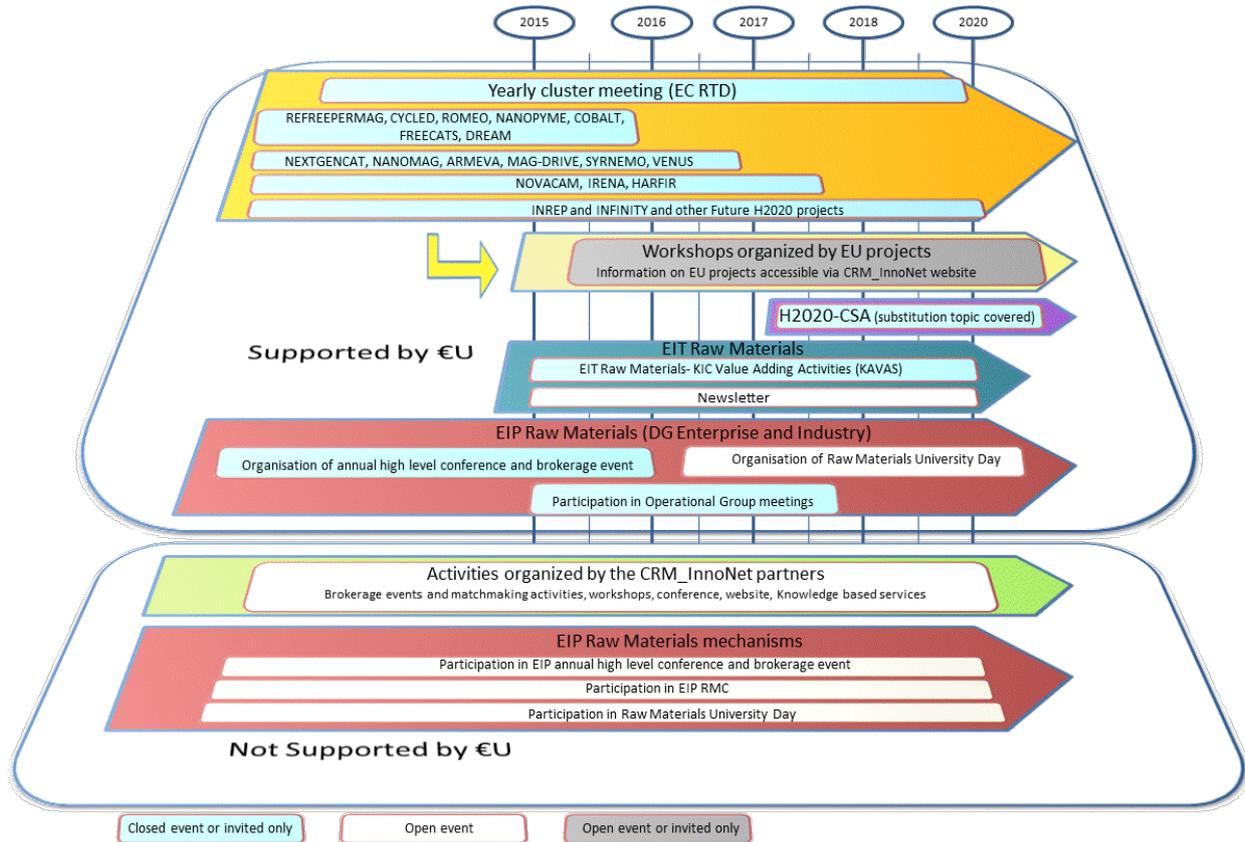


Figure 11: Summary of the identified mechanisms ensuring the sustainability and endurance of the Innovation Network on substitution of CRMs for the coming years.

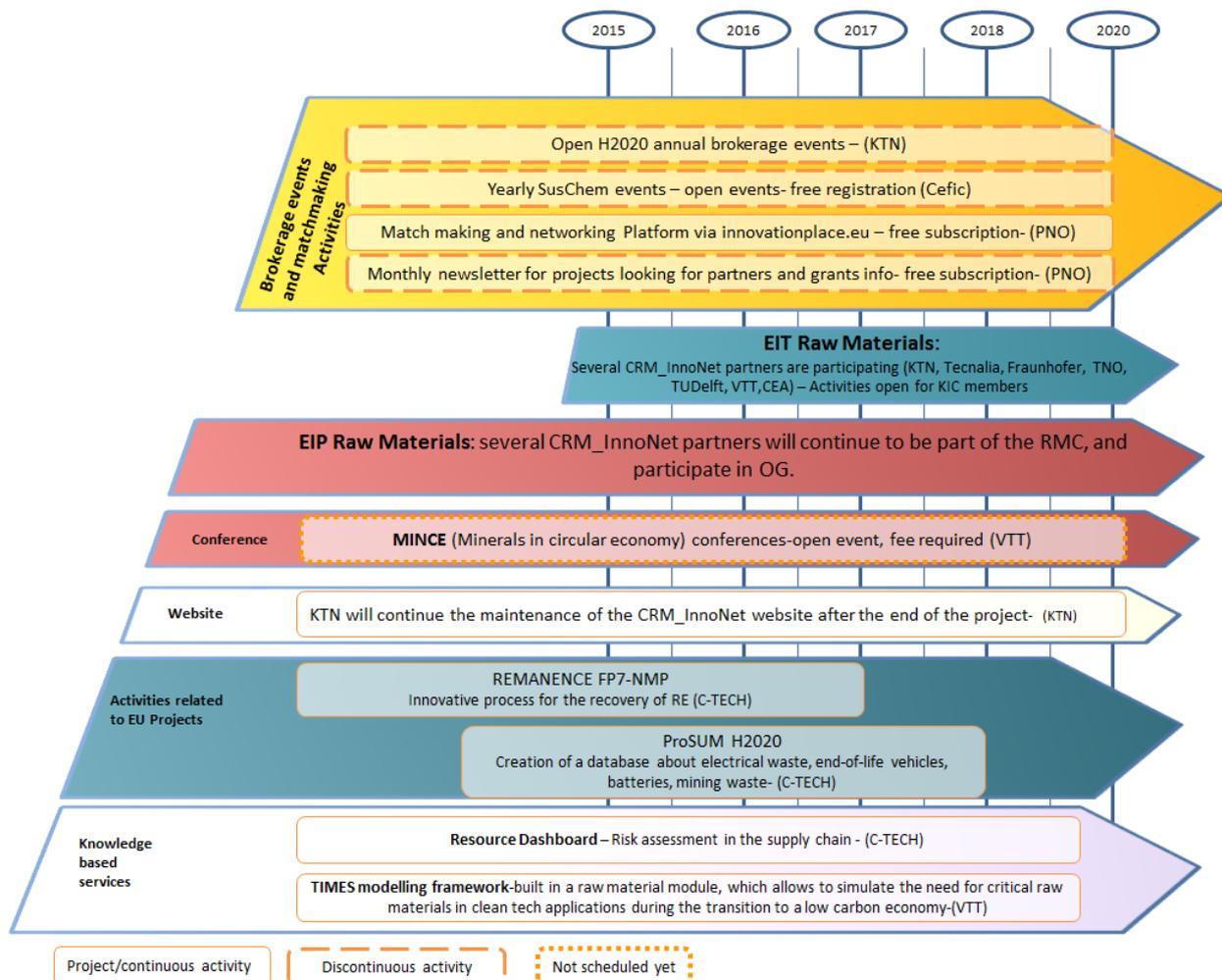


Figure 12: Summary of the activities foreseen by the CRM_InnoNet partners to contribute to the sustainability of the Innovation Network on substitution of CRMs for the coming years.

The following two deliverable reports for WP6 have been published on the project website (www.criticalrawmaterials.eu/documents):

- N. Akil, Deliverable Report D6.1 “Final report on potential financing mechanisms and pole working structure and methodology”
- N. Akil, Deliverable Report D6.2 “Final report on lessons learnt after the organisation of the three foreseen workshops”

POTENTIAL IMPACT

Please provide a description of the potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results. The length of this part cannot exceed 10 pages.

1. Impact

CRM_InnoNet was initiated as a project aiming to collect and elaborate data and make available to the EU Institutions and Member States accurate pictures, analysis of needs, threats and opportunities and proposals for further action in the field of substitution of Critical Raw Materials (CRMs). Raw Materials are essential for the sustainable functioning of the European society. Key European sectors such as construction, chemicals, automotive, aerospace, machinery and equipment which provide a total value added of € 1,324 billion and employment for some 30 million people all depend on access to raw materials.

Europe has responded to the raw materials issue with the Raw Materials Initiative (RMI), which is fundamentally based on three pillars:

- Access to raw materials on world markets at undistorted conditions.
- Foster sustainable supply of raw materials from European Sources.
- Reduce the EU's consumption of primary raw materials through resource efficiency including substitution.

CRM_InnoNet set out to contribute to the successful implementation of the Raw Materials Initiative and related activities through:

- Collection and elaboration of data and formulation of ideas for possible novel actions with high European common interest
- Identification and prioritisation of R&D needs in order to support the EU strategic approach regarding the substitution of critical raw materials
- Improved coordination in research and innovation actions in the field of raw materials substitution
- Increased efficiency and effectiveness of the EU research activities in the field of substitution of CRM
- Creation of one leading Innovation Network with the potential to support and enhance the competitiveness of the EU industry and economy

These goals have been achieved through the following actions delivered by CRM_InnoNet:

- Comprehensive mapping of existing initiatives at the Member State and European level in relation to substitution of CRM, including existing collaborations outside Europe.
- The establishment of a methodology and prioritisation strategy to address the essential factors (technological and non-technological) to consider in the area of substitution of CRM so to elaborate a realistic and useful roadmap.
- Elaboration of a European roadmap for substitution of CRM, which considers the necessary technological, innovative and non-technological factors to be addressed in key sectors (i.e. Transport, ICT, Energy) for achieving the substitution of CRM in the medium and long term (timeline 2015 - 2030)
- Elaboration of a recommendation document for stakeholders and policy makers constituting an overarching vision to offer strategic recommendations for CRM substitution. The document contains detailed conclusions resulting from the open and intense dialogue with

all relevant value chain actors and includes ideas for future actions and proposes initiatives at European level.

- Creation of one Innovation Network as an open and dynamic forum to incorporate essential players and actors from a global perspective, ensuring widest possible endorsement of the roadmap and recommendations by relevant actors across the value chain as well as reflecting all important factors.
- Providing a strategically supportive reference project and platform for existing or future initiatives at a European level (i.e. European Raw Materials Initiative, EIP Raw Materials, etc.) as well as at the level of Member States.

The mapping of existing initiatives relating to substitution of CRMs has not only focused on initiatives within the European borders, but has also considered existing collaborations outside Europe (i.e. bilateral, multilateral, etc.). Special attention has been paid to the identification and study of those initiatives with emerging resource-rich economies such as China, resource dependent countries such as the US and Japan, and also with key players such as South America. In this manner, the mapping performed constitutes valuable input for helping to implement so-called raw materials diplomacy.

The roadmap for substitution of CRMs has contributed to identify all critically relevant innovation factors (technological and non-technological) that will influence the future substitution of CRMs attending to sector particularities and synergies. The roadmap has established the basis for concrete actions and pathways leading to the development of new technologies, production processes, regulations and standards that will strengthen European Industrial critical sectors and will positively contribute to resource efficiency and eco-innovation. Moreover the roadmap offers opportunities for an increase in European competitiveness and innovation and a decrease in future European dependency on CRM that will affect fundamental European Industrial sectors.

Within the document on recommendations, CRM_InnoNet has proposed measures to increase the effectiveness and efficiency of the EU research activities in the field of CRM substitution. The document has taken into account the mapping of existing initiatives across the European area as well as those of special relevance outside Europe. In this manner, an overarching vision to offer strategic recommendations has been formulated against an analysis of best practices and detection of missing R&D policy elements, initiatives or actions therefore presenting a unique opportunity to increase the effectiveness of policies and resulting innovation moving forward.

The creation of the Innovation Network has set the basis for the constitution of a permanent working and monitoring group that can evaluate the progress made in the field of substitution of CRMs and also promote and propose further actions in connection with supporting global EU and member state policy directions. The Innovation Network has served as a platform to coordinate cooperatively the efforts of all possible actors across the value chain in the field of substitution of CRMs and has incorporated essential players and actors from a global perspective seeking to initiate and/or enhance international collaboration.

The main contributions made by CRM_InnoNet and their associated impact are summarised in table 2.

Table 2: Summary of CRM_InnoNet main impact contributions

CRM_InnoNet main contribution	Main impact
Elaboration of a European mapping of initiatives on substitution of CRM.	<p>Identification of key initiatives and champions across the European Research Area.</p> <p>Alignment and connection of the project with Member States and EU initiatives.</p> <p>Provided an up-to-date database to policy makers and R&D&I actors and sectors.</p> <p>Identified synergies and cooperation routes; avoid duplication of efforts and initiatives.</p>
Elaboration of a mapping of international (not limited to the EU perimeter) of initiatives on substitution of CRM	<p>Provided input to policy makers for enhancing international cooperation outside EU perimeter.</p> <p>Contributed to Raw materials diplomacy policy.</p>
Elaboration of a methodology and prioritisation approach in the field of substitution of CRM	<p>Clear and holistic guidelines for the elaboration of a roadmap.</p> <p>Identification of potential synergies and sector specificities and needs.</p>
Elaboration of a European roadmap for substitution of CRM	<p>Established a reference document considering technological and non-technological innovation factors for mid and long term.</p> <p>Provided targets agreed by all value chain actors in key European specific industrial sectors that can be monitored and updated over time.</p> <p>Provided initial guidelines for the development of new industrial initiatives and new competitive markets.</p>
Creation of the Innovation Network	<p>Provided an open, interactive, dynamic and durable observation and monitoring platform for all EU and international relevant actors.</p> <p>Provided a reference platform that has contributed to coordination of efforts carried on at EU and National level on a continuous basis.</p>
Elaboration of a recommendation document for stakeholders and policy makers	<p>Provided a comprehensive and holistic reference document that contributes to fostering of on-going and future initiatives on CRM.</p> <p>Provided a series of recommended future actions endorsed by a large collective of European key players in critical sectors that will contribute to alignment of efforts.</p>

2. Dissemination Activities

Overall, CRM_InnoNet, after 32 months of activity, has become well known as a valued reference for those stakeholders related to CRM substitution and in general critical raw materials, since one of the main messages conveyed was that “CRM substitution is only another alternative to address the raw materials challenge in Europe, together with primary supply and recycling”.

Project reports such as “The critical raw materials substitution profiles report” (D3.3) are very appreciated by the scientific community and have already triggered some initiatives concerning substitution of some materials for specific applications.

Moreover, the report “County Profiles” (D3.2) has highlighted the current situation of the EU and other selected countries. It was noted that, in general, not many EU countries have a Raw Materials strategy and even less consider substitution among the solutions, which is an indicator of the importance given to this topic at Member States level and where there is room for improvement through continued awareness raising. Some national bodies contacted during the project life have, as a result, initiated the process to define their own strategy demonstrating the opportunity for (future) impact of the project in influencing policy.

The preparation of the supply chain analyses for 3 sectors of high-relevance to the EU economy, the elaboration of the roadmaps for the 5 selected high-priority application areas and the development of a set of policy recommendations have reached many experts from Industry and academia as well as policy makers. These activities have thus increased awareness of the potential risk for the European economy in case of no supply/higher prices for the CRM used in their production and the message has been conveyed that consequences could be the lack of competitiveness or ultimately, delocalisation from EU territory.

Furthermore three strategic workshops of the Innovation Network have not only raised awareness of the issues of CRM substitution, but an interactive and dynamic platform for stakeholders engaged in the CRM substitution topic has been created. For the first time a community focused on the substitution topic has been brought together and first foundations for critical mass in the area have been laid.

Overall, 7 project events were held, namely 3 Innovation Networks workshops (WP6), 1 Supply Chain Analysis workshop (WP4), Vision Workshops (WP5), Policy workshop (WP8) and the Final Project Conference (WP7). The 7 events totaled 602 registrations representing 320 unique organisations primarily from the EU countries. It is important to highlight that also international collaboration has been established with the Critical Materials Institute (USA) as a result of the project outputs.

A wide range of communication and dissemination tools have been developed and utilised by the project partners. Communication tools include the attractive and interactive project website (www.criticalrawmaterials.eu) and promotional materials (i.e. project fliers and brochure, videos, Prezis, roll-up banners, press releases, quarterly newsletter and social media, such a blogs, twitter and LinkedIn). In particular the project website has consistently grown in number of visitors each month and by project end a total of 525 individuals from 393 organisations had registered via the project website with key outputs by the project ranking among the most popular resource accessed.

The communication tools have been deployed throughout the project to introduce and promote the project, its objectives and key outputs. In addition a total of 57 project news articles have been published in respected relevant journals, the trade press and on websites.

Dissemination activities focused on sharing the project’s objectives and results, as well as future recommendations with the stakeholders related to CRM substitution.

To achieve this goal Consortium members presented the CRM_InnoNet at a total of 46 external conferences and events over the course of the project. The reaching potential of such presentations has been significant, e.g. to illustrate the annual Spring / Autumn meetings organised by the European Materials Research Society (EMRS) offer on average 25 topical symposia. They are widely recognised as being of the highest international significance and are the greatest of their kind in Europe with about 2,500 attendees every year. EMRS itself has more than 3,200 members from industry, government, academia and research laboratories, who meet regularly to debate recent technological developments of functional materials.

An additional activity that has strongly contributed to the dissemination of the project is the participation of some Consortium members in specific working groups or task forces relevant for the topic, such as the Operational Groups of the EIP on Raw Materials, The Ad-hoc Working Group on the revision of the CRM List and ERECON.

The participation of project partners in the Trilateral EU-US-Japan Conferences on Critical Raw Materials organised by the EC in collaboration with the Critical Materials Institute (CMI) was the first step to further develop the cooperation in substitution between CMI and some CRM_InnoNet partners.

Furthermore, delivered dissemination activities have initiated the relationship with other relevant communities, e.g. EMIRI, ERRIN, NANOFutures, the Graphene Flagship, Photonics 21, ESTEP, SPIRE, etc.

At the end of the project, a total of 127 communication and dissemination activities have been reported (*c.f.* table 3).

Table 3: Communication and dissemination activities summary

Type of activity	Number
Articles published in the popular press	57
Exhibitions	6
Flyers	10
Oral presentation to a scientific event	11
Oral presentation to a wider public	9
Organisation of Conference	2
Organisation of Workshops	2
Posters	5
Presentations	6
Press releases	6
Publication	3
Videos	2
Web sites/Applications	8
TOTAL	128

The targets for project dissemination as set out in the initial dissemination plan have not only been met but project performance exceeded these targets in many case as shown in table 4.

Table 4: Overview of CRM_InnoNet dissemination metrics, targets and achievements

Metric	Target	Achievement
Project website hits	400 per month	1067 (Average), 1485 (peak in April 2014)
Citations in search engines	50	1762 citations (94 out of 1st 100 citations confirmed related to project)
Dissemination at major external event	7	9
Project on stakeholder website	30	>30 sites via Google Search
Workshop attendees	220 across 6 workshops	602
Organisations joining Innovation Network (formerly Pole of Excellence) via project website	50 industry, 50 academic, 50 others	393
References in publications/news articles	40	57
Newsletters	10	10
Press release	1	7
Materials for journalists	1	2
Additional dissemination at minor events	0	37

In summary, a range of communication tools have been developed by the project and been used by project partners to support a variety of dissemination activities. Two key components of the project CRM_InnoNet have ensured execution of an integrated project dissemination plan:

- The project consortium representation of main European actors and its direct connections to key stakeholders in a pan-European manner.
- Division of the project into interactive and timely strategically structured work packages allowing for an efficient bi-directional flow of information both internally and externally.

By taking a proactive approach to dissemination, barriers have been overcome where at the beginning of the project many of the potential solution providers did not associate themselves with 'the field of substitution' and were unaware of the issues of critical raw materials.

The dissemination activities implemented by CRM_InnoNet partners have ensured reaching as wide an audience as possible and as such, CRM_InnoNet has effectively engaged an audience composed of:

- **The EU (and beyond) CRM-related scientific community** (Academia, Research Establishments across multiple disciplines including chemistry, physics, engineering and design)
- **The EU (and beyond) CRM-related applied research community** (industry including SMEs and large corporations)
- **The non-scientific CRM-related stakeholders** such as NGOs, media, non-profit organisations, standardisation bodies (i.e. CEN), etc.
- **National Funding Agencies and Ministries**

The main impacts of dissemination actions implemented by CRM_InnoNet are summarised in table 5.

Table 5: Summary of the CRM_InnoNet main dissemination actions and associated main impact

Dissemination action	Main impact
Elaboration of a project website with interactive capabilities.	Extensive reaching potential and contact with all European communities in the area of CRMs. Concrete reference platform to interact with stakeholders allowing exchange of information (leaflets, links, newsletters) both sides (project members towards stakeholders and vice versa). Reference platform for communicating and disseminating the project progress and foreseen activities.
Organisation of WP specific workshops.	Ensured the active participation of engaged stakeholders in the project development from the start. Ensured the elaboration of useful and endorsed action methodologies and results.
Participation of Consortium members in key events along their respective reaching perimeter.	Ensured the full dissemination of the project results. Ensured a wide European coverage wrt audience and sectors. Increased the engagement of active stakeholders as members of the Innovation Network.
Direct networking and contact with especially relevant EU bodies (ETPs, JTIs, Industrial Sector Organisations, etc).	Expanded and increased the full action potential of the Innovation Network. Promoted the active involvement of stakeholders in the project.

<p>Progressive creation of the Innovation Network.</p>	<p>Established a step-wise methodology for involving key actors and engaged them in a proactive participation.</p> <p>Provided an open, interactive, dynamic and durable observation and monitoring platform for all EU and international relevant actors.</p> <p>Analysed the contribution and help of different stakeholders for the possibility of continuation of the Innovation Network, as well as setting agreed targets and actions.</p> <p>Provided a reference platform that has contributed to coordinate efforts carried out at EU and National level.</p> <p>Provided an interactive platform to take into account the voice and perspective across the whole value chain of substitution of CRM.</p>
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3. Summary

CRM_Innonet has delivered a comprehensive mapping of European substitution activities, a roadmap for the substitution of critical raw materials in five key application of economic importance to Europe and a set of policy recommendations.

A secure and affordable supply of raw materials is essential to European industry. Many key raw materials are entirely imported into Europe. The health of the European economy and the ability of Europe to meet its green energy ambitions are dependent on access to critical raw materials. Europe has responded to the raw materials issue with the Raw Materials Initiative, which aims to foster secure supply by increasing production in Europe, securing access to resources outside of Europe and increasing resource efficiency and substitution. CRM_InnoNet has contributed to the successful implementation of the Raw Materials Initiative and related activities through:

- Collection and elaboration of data and formulation of ideas for possible novel actions with high European common interest
- Identification and prioritisation of R&D needs in order to support the EU strategic approach regarding the substitution of critical raw materials
- Improved coordination in research and innovation actions in the field of raw materials substitution
- Increased efficiency and effectiveness of the EU research activities in the field of substitution of CRM
- Creation of one leading Innovation Network with the potential to support and enhance the competitiveness of the EU industry and economy.