European Commission

Channelling knowledge from European projects into the Raw Materials Information System (RMIS)

Focus on advanced materials and their potential to substitute for Critical Raw Materials: policy context & needs, ongoing research & perspective

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Abstract

The Joint Research Centre (JRC) and the European Health and Digital Executive Agency (HaDEA) held the Raw Materials Information System (RMIS) workshop on the 9th and 10th of October 2024, in Brussels. On the second day, the event focused on the role of advanced materials in reducing reliance on critical raw materials (CRMs) to meet the EU's goals for industrial sustainability and competitiveness. Key representatives from the European Commission, research institutions, industry and EU-funded projects participated and contributed to the discussion. In particular, research outputs presented during the day have shown that innovations which can affectively strengthen resource security and promote circular economy practices can help meeting the ambitions set by most recent policy documents on critical and advanced materials. Continued development of advanced materials is vital to securing Europe's industrial autonomy toward a sustainable, low-carbon economy. The workshop successfully fostered collaboration and insight sharing among stakeholders, reinforcing collective efforts toward a resilient and sustainable European industry. It also helped identify a number of areas where collaboration and synergies with specific projects will be established and will bring new content into the JRC's RMIS.

1 Introduction

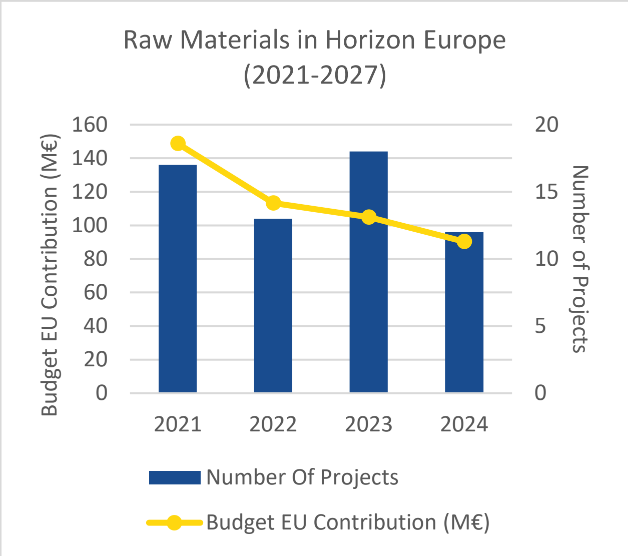
The European Union’s reliance on critical raw materials (CRMs) poses significant strategic and environmental challenges, given the supply risks and environmental impacts associated with these materials. To address these challenges, the EU has implemented the European Green Deal and Critical Raw Materials Act (CRMA), setting ambitious goals to reduce CRM dependency, enhance industrial resilience, and support sustainable development. Central to this strategy are advanced materials, which enable CRM reduction across key sectors. The recent Communication on ‘Advanced Materials for Industrial Leadership’ (COM (2024) 98) highlights the EU's commitment to creating a secure and inclusive ecosystem for advanced materials and fast-tracking innovations across four strategic areas: energy, mobility, construction, and electronics.

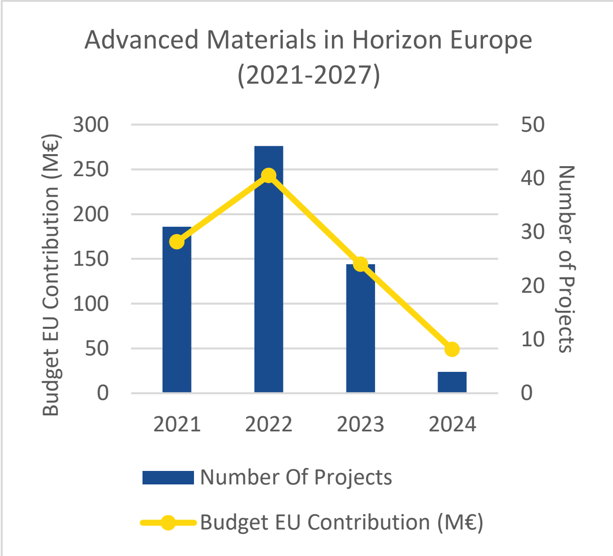
In this context, the Joint Research Centre (JRC) and the European Health and Digital Executive Agency (HaDEA) organised the 2024 Raw Materials Information System (RMIS) workshop, held in October in Brussels. The workshop aimed to channel insights from European projects into the RMIS platform to support secure and sustainable CRM management. The event emphasized two key themes: knowledge synthesis for critical and strategic raw materials (first day) and the potential of advanced materials to reduce reliance on CRMs (second day). The first day featured high-level policy discussions on the role of CRMs and strategic materials in EU competitiveness, with representatives from key EU bodies, academy and EU-funded projects underscoring how these initiatives contribute to CRM efficiency, recycling, and substitution, aligned with the EU sustainability goal.

The second day of the workshop focused on the role of advanced materials in reducing CRM dependency, with participants examining research and practical solutions across key sectors. Experts from JRC, HaDEA, and DG RTD outlined ongoing research initiatives to reduce CRM usage, emphasising the potential of advanced materials to support strategic EU transitions. Notable institutions involved were the European Materials Research Society (E-MRS), the Italian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA), the European Technology Platform for Advanced Engineering (EuMaT), Innovative Advanced Materials for Europe (IAM4EU), and the European Innovation Council and SMEs Executive Agency (EISMEA). These organisations play a critical role in CRM reduction by driving cutting-edge research and supporting innovations that meet EU policy objectives.

The HaDEA (B3 Industry Unit) presented the current state of the raw and advanced materials portfolios funded by Cluster 4 (Digital, Industry and Space) in H2020 and Horizon Europe. The Raw Materials portfolio includes 60 projects and a total EU contribution of almost 460 million euros, covering the entire value chain for the sustainable supply of raw materials. And, the Advanced Materials portfolio contains 105 projects and a total EU contribution of about 600 million euros (**Figure 1**).

Figure 1. Raw Materials and Advanced Materials projects in Cluster 4 Horizon Europe (2021-2027).





€457 102 029

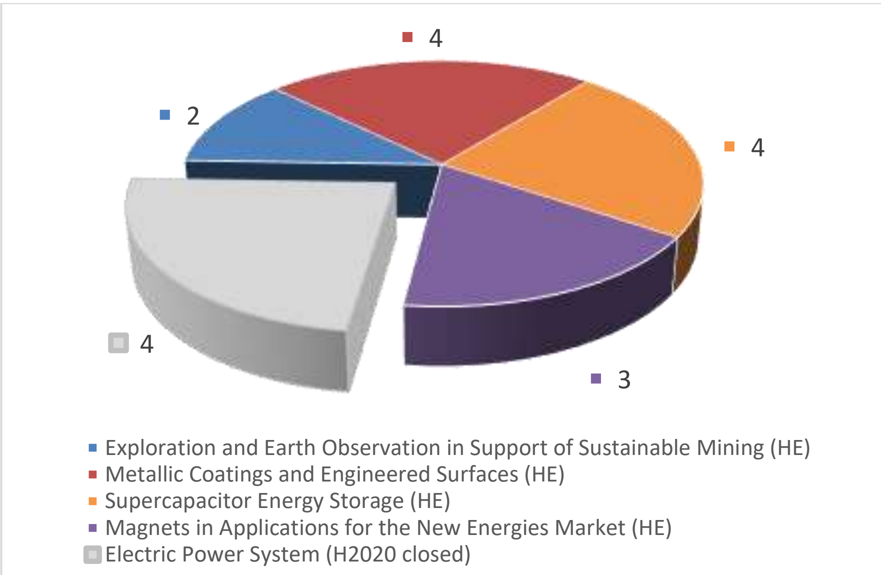
€605 657 009

Source: (HaDEA, own analysis)

It can be seen the massive frontloading that has been organised in the research activities in these two fields, in the very first years of the Horizon Europe work programme. In total, HaDEA is currently managing 165 projects with a total of 1 062 759 038 euros EU contribution.

In the frame of knowledge needs identified by the Critical Raw Materials Act, HaDEA focuses also on the knowledge on substitution of Critical Raw Materials with Advanced Materials. Currently, there are 13 projects that operate in this specific area of substitution, and they articulate under different topics of Horizon Europe Cluster 4. Also, there are 4 projects that recently ended, funded under the H2020 legacy (**Figure 2**).

Figure 2. Advanced Materials: substitution of Critical Raw Materials.



Source: (HaDEA, own analysis)

Furthermore, HaDEA presented the Advanced Materials report 2024, which covers 155 projects under Horizon 2020 and Horizon Europe with an investment of €842 million. This report further underscores the EU's commitment to CRM reduction, green production, and circular economy practices, with project portfolios that support EU resilience and sustainability goals.

This report captures the key insights from the RMIS workshop, offering a comprehensive overview of current research, policy priorities, and the practical applications of advanced materials for CRM reduction across strategic sectors.

2 Results and Findings

This report focuses on analysing EU-funded projects and expert presentations from the 2024 RMIS workshop, with the goal of reducing the use of critical raw materials (CRMs) in strategic sectors.

The selected project focuses on mobility, electronics, construction, and energy to understand its specific contributions to CRM reduction, the advanced materials applied, and the anticipated impact on EU policy goals related to CRM independence and environmental sustainability.

Project presentations highlighted practical applications of advanced materials in CRM reduction, featuring BEETHOVEN, NICKEFFECT, MUSIC, and PROMET-H2. Focusing on a sectoral approach allows for a comprehensive examination of CRM dependencies across diverse industries, enabling targeted strategies that align with sector-specific requirements. Description of the projects can be found in the annexes.

Mobility Sector

Project: BEETHOVEN (Adrián Quesada)

— Findings: The BEETHOVEN project identified ferrite-based composites and high-entropy alloys (HEAs) as viable CRM-free alternatives to rare earth elements (REEs) in high-performance magnets for electric motors and wind turbines. These advanced materials maintain essential magnetic properties required for efficient performance, eliminating the need for CRMs like neodymium and dysprosium, which are typically imported and vulnerable to supply chain risks.

— Implications: BEETHOVEN's advancements contribute significantly to the EU's goals for industrial resilience and sustainability. By reducing dependence on imported REEs, this project aligns with strategic objectives for electrification and green energy, especially in the automotive and renewable energy sectors. The use of ferrite and HEA-based magnets supports the EU's Green Deal and circular economy initiatives by decreasing environmental impacts associated with CRM extraction and processing.

Focus on Mobility: Beatriz Ildefonso, Circularity and Materials Manager, CLEPA – The European Association of Automotive Suppliers

— **Findings**: The automotive sector is highly dependent on critical raw materials (CRMs) such as cobalt, graphite, nickel, and rare earth elements (REEs), essential for electric vehicle batteries and motors. To mitigate this dependency, the industry is increasingly utilizing advanced materials like high-strength aluminium, plastics, and composites, which reduce vehicle weight and enhance energy efficiency. Additionally, improved recycling practices are being adopted to recover CRMs from components like magnets and batteries, aligning with EU regulations on durability and circularity.

— **Implications**: By integrating advanced lightweight materials and enhancing CRM recycling, the automotive sector can address CRM scarcity while supporting the EU's sustainable mobility goals. This approach not only improves energy efficiency, particularly in electric vehicles, but also promotes circular economy principles, reducing waste and maximizing resource reuse.

Electronics Sector

Project: NICKEFFECT (Francisco Alcaide Monterrubio)

- **Findings:** The NICKEFFECT project has pioneered the use of nickel-based coatings to replace platinum (Pt) in digital storage devices and catalytic applications. This substitution reduces the need for platinum group metals (PGMs) by 85%, maintaining efficiency in applications such as PEM fuel cells and MRAM (magnetoresistive random-access memory). By achieving high performance with significantly less platinum, NICKEFFECT addresses the CRM dependency common in high-tech electronics.
- **Implications:** The adoption of nickel-based materials in place of Pt mitigates CRM dependency in electronic and catalytic applications, lowering costs and reducing the risks associated with PGM supply volatility. This advancement aligns with EU goals to decrease CRM reliance across technology sectors, contributing to sustainable electronics development and enhancing resource resilience.

Focus on Electronics: Vincent Consonni, CNRS Research Director, Head of NanoMAT Team

- **Findings**: Consonni highlighted the electronics sector's reliance on critical raw materials (CRMs) such as gallium, indium, yttrium, and cerium, commonly used in devices like LEDs and smart sensors. He emphasized advanced materials like gallium nitride (GaN) and indium gallium nitride (InGaN), known for their role in high-performance electronics, enabling device miniaturization and improved energy efficiency. These materials are essential for modern, compact electronic devices with reduced energy demands.
- **Implications**: Consonni discussed alternative materials, including ZnO nanowires, as potential substitutes to reduce CRM dependency in future electronic components. By promoting sustainable alternatives, these materials enhance device performance and miniaturization without extensive reliance on CRMs, supporting a more resilient electronics supply chain.

Construction Sector

Focus on Construction: Gian Andrea Blengini, Earth Sciences Department (DST), University of Turin

- **Findings**: The construction sector relies on critical raw materials (CRMs) like niobium and antimony for structural integrity and safety. Niobium is used to reinforce steel, enabling the creation of thinner, lighter structures that reduce overall steel use while maintaining durability and lowering carbon emissions. Antimony serves as a vital flame retardant, essential for building safety but with supply and environmental challenges. Other CRMs commonly used in construction include copper for electrical wiring, tungsten for high-durability tools, chromium for corrosion-resistant coatings, and bismuth for specialized alloys, each contributing to structural strength, safety, and longevity.
- **Implications**: Integrating advanced materials, such as niobium-enhanced alloys, allows the construction sector to achieve higher CRM efficiency, aligning with the EU’s circular economy and sustainability goals. This approach reduces reliance on imported CRMs, lowers carbon footprints, and enhances resource efficiency in vital infrastructure projects.

Energy Sector

Project: MUSIC (María Arnaiz)

- **Findings**: The MUSIC project focuses on developing sustainable sodium-ion capacitor (SIC) technology as a CRM-free alternative to conventional lithium-ion energy storage systems. By using bio-waste-derived activated carbon and fluorine-free binders, MUSIC creates CRM-free components for supercapacitors, aiming to enhance energy density, cost-effectiveness, and environmental sustainability.
- **Implications**: By leveraging advanced materials that avoid CRMs, MUSIC reduces CRM dependency in energy storage solutions, aligning with EU goals for circularity and resource efficiency. This innovation supports sustainable electrification and promotes low-carbon transitions in applications ranging from consumer electronics to transportation.

Project: PROMET-H2 (Daniel García Sánchez)

- **Findings**: The PROMET-H2 project advanced proton exchange membrane water electrolysis (PEMWE) technology for hydrogen production, emphasizing CRM reduction and cost efficiency. Key achievements included a tenfold reduction in iridium content in catalyst layers by using iridium on antimony tin oxide (ATO) formulations, reaching a 90% CRM reduction. The project also replaced titanium with stainless steel in critical components, further decreasing reliance on CRMs while maintaining high performance and durability. Additionally, PROMET-H2 developed a novel, environmentally friendly recycling process for platinum and iridium, achieving recovery rates of 100% and 60%, respectively.
- **Implications**: By significantly reducing CRM usage and enhancing recyclability, PROMET-H2 aligns with EU goals for sustainable energy technology and circular economy practices. The project supports Europe’s hydrogen strategy, providing a cost-effective, CRM-efficient pathway for renewable energy storage, which is essential for the EU’s green energy transition

While these advanced materials demonstrate promising potential, several uncertainties could affect their impact. Market readiness remains a concern, as the time required for commercialization and widespread adoption across sectors may be longer than anticipated. Additionally, supply chain stability is critical; fluctuations in the availability of alternative materials could challenge the feasibility of CRM reduction, especially amid market volatility. Finally, the integration of these new materials into existing manufacturing and production processes may necessitate technical adjustments, potentially delaying immediate benefits.

3 Conclusions

The 2024 RMIS Workshop highlighted the pivotal role of the Raw Materials Information System (RMIS) in advancing critical raw material (CRM) reduction, essential to achieving the EU's sustainability and strategic autonomy goals. Organized by the Joint Research Centre (JRC) in collaboration with HaDEA, the workshop emphasized the integration of advanced materials across key sectors such as mobility, construction, electronics, and energy. Expert talks by Vincent Consonni on CRM-efficient electronics, Gian Andrea Blengini on CRM applications in construction, and Beatriz Ildefonso on sustainable materials in mobility showed how efforts to reduce CRM and sector-specific approaches to resource efficiency could have a real effect.

The EU-funded projects demonstrated how advanced materials could reduce CRM dependency in these strategic areas. Projects like BEETHOVEN, NICKEFFECT, PROMET-H2, and MUSIC highlighted CRM-reduction and CRM-efficient solutions across applications critical to European industry. BEETHOVEN's ferrite-based magnets, NICKEFFECT's nickel coatings, and PROMET-H2's iridium-free electrolyser components each offer sustainable alternatives in mobility, electronics, and energy. The MUSIC project, focusing on CRM-free sodium-ion capacitors, further supports the EU's transition to sustainable energy storage solutions. The diverse contributions across sectors—from CRM-free materials in mobility and electronics to CRM recovery processes in energy—illustrate a comprehensive approach to CRM reduction, addressing supply chain vulnerabilities, minimizing environmental impacts, and supporting the circular economy.

Realizing the full benefits of CRM-efficient materials will require continued research, investment, and collaboration to scale these innovations across European industries. As advanced materials technologies progress, they will play a crucial role in meeting the EU's sustainability, autonomy, and industrial resilience objectives. By fostering these solutions, the EU can reinforce its leading position in the global industrial landscape, ensuring sustainable growth and resource security for the future.

As an outcome of the workshop, and drawing on a number of collaboration with specific EU projects, a new thematic section focused on advanced materials will be included in the RMIS.

List of figures

Annexes

Project BEETHOVEN

Advanced materials for the automotive sector - Beatriz Ildefonso.

Potential of advanced materials in electronics sectors - Vincent Consonni.

Project MUSIC

Project PROMET-H2

Modern technologies required for the transition to a climate-resilient sustainable green and digital future (wind generators, electric motors) heavily rely on rare-earth (REE) permanent magnets. However, with China covering 98% of the supply to Europe in 2022, the continent is left in an extremely vulnerable position with respect to these critical raw materials. In this framework, the BEETHOVEN project seeks to address the challenge brought forward in the Topic description to reduce the amount of REE employed in the new energy sector. The main goal of the project is to develop innovative and sustainable advanced magnetic materials that substitute REE in the energy and transportation sectors. We will work on developing and upscaling 3 types of magnetic phases: high-entropy alloys, ferrite-based composites and W-type ferrites, that could be deployed at large scale in the permanent magnets market. Substitution will be demonstrated in final applications by developing REE-bonded magnets for automotive components, and by designing and building prototypes for a REE-lean wind generator, a REE-free flywheel and a REE-free/lean e-motor for electric vehicles. A team of experts from 14 partners and 10 countries -with demonstrated experience working collaboratively at the frontier of knowledge in the permanent magnet sector- has been assembled.

The main outcomes of the project are expected to be:

OUTPUT/RESULT	ADDED VALUE
NOVEL REE-FREE/-LEAN MAGNETIC MATERIALS BASED ON FERRITES AND HEAS	New gap magnet powder materials to be commercialized from Europe.
IMPROVED REE-FREE/LEAN MAGNETS	25% increased revenue (600 k€ by 2033) and 15% workforce increase (30 employees)
REE-FREE/-LEAN DEVICES AND MAGNETS & SUSTAINABILITY ASSESSMENTS	2,100 - 4,900 tons by 2033. 85% / 20% reduction of kg CO_2-eq for ferrites/HEA magnets
RECYCLING STRATEGIES (ER9)	Enhance recycling rate of PMs in production facilities by at least 15%

The BEETHOVEN outcomes can contribute to RMIS as follows:

- **Security of supply**: Recycling strategies for Sr and Nd-based materials
- **Raw Materials Profiles**: Include secondary sources of materials ($SrFe_{12}O_{19}$)
- **Technology and sector profiles**: Updated list of magnetic materials used in wind turbines, e-motors and flywheels.
- **Critical, Strategic and Advanced Materials**: Update factsheet with novel materials and measured properties.
- **Raw Materials in Vehicles**: Updated projections on use of NdFeB alternatives in the vehicle sectors.
- **Materials Systems Analysis**: Flow of recycled material, Flow projections of novel materials.
- **Future Demand for Raw Materials in Emerging Technologies:** Estimations on potential demand of novel and existing magnetic materials

JRC / HaDEA Technical Workshop Advanced materials for the Automotive sector

Beatriz Ildefonso, CLEPA, 10 October 2024

- Automotive suppliers are key technology providers in the context of the EU decarbonisation targets but also, industrial competitiveness.

- The automotive sector is complex and based on strict quality standards which are highly regulated ensuring safety and durability of automotive vehicles.

- Understanding key trends is crucial to map future material needs:

Trends (non-exhaustive)	Implications on automotive material needs
Electrification	Increased use of battery elements (e.g.cobalt, graphite, and nickel) but also copper EVs are typically 200-250kg heavier than ICE equivalents Lightweight materials to counteract (e.g. aluminium, plastics)
Circular Economy	Ecodesign to automotive design (whole lifecycle approach) Mandatory use of recycled plastic and potentially for steel, aluminium and permanent magnet Mandatory use of recycled battery materials cobalt, lead, lithium and nickel
Toxic-free Environment	Durability vs environmental persistence e.g. PFAS; Legacy substances in recycled material
Supply Chain Resilience	Benchmarks for domestic capacities for CRMs and incentives to development of alternatives Responsible and sustainable sourcing

- A whole lifecycle approach is needed when developing advanced materials that are suitable for the automotive specifications. CLEPA identified three main pillars of research needs:
  - Solutions for natural resource efficiency: simplified product design, which must cater not only to the performance and durability requirements but also to repair dismantling and recycling. Alternatives are needed to replace scarce and critical materials as well as for performance critical substances with hazardous profiles (e.g. PFAS).
  - Solutions for lifetime maximisation: materials and design that avoid loss of performance especially for critical components (e.g. motors and battery). Improved brake and tyre wear for instance through new additives and coatings. Better understanding of material and component aging to identify failure root causes and define preventive maintenance strategies
  - Solutions to give resources a new life: better understanding of quality level of end-of-life components, and acceptability criteria for recovered parts and overall, improved separation and sorting technologies to facilitate access to materials especially for CRMs, such as rare earths. Alternatives to magnesium coatings for corrosion resistance, in order to improve recyclability. Materials that are able to maintain quality after multiple loops of recycling including dedicated strategies for plastics rare-earth magnets and other critical raw materials

- The recent wave of environmental legislation is exposing the limitations of existing materials available to the industry. Advanced materials are needed to fill in the gaps.

Vincent Consonni

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The development of advanced materials in electronics sectors mainly relies on two complementary paradigms aiming at miniaturizing the devices as much as possible while improving their performance and cost, as well as diversifying their functionalities in the field of Internet of Things (IoT), through the respective "More Moore" and "More than Moore" approaches [1]. Whereas the former is based on the development of logic and memory technologies to manage instant and big data, the latter focuses on the development of nondigital functionalities, usually involving smart sensors, smart energy & energy harvesting, or wearable flexible electronics. Here, an overview of the different advanced materials under development will be briefly achieved along with the typical approaches driving the field of materials science (e.g. new materials, nanoscale building blocks, …).

To illustrate the approach followed in materials science, a special emphasis will be placed on inorganic white light emitting diodes (LEDs), where critical raw materials in commercially available devices as seen in Fig. 1 play a significant role and raise issues [2]. After identifying the nature of critical raw materials in white LEDs, the different alternatives developped in basic research to reduce their amount and/or partially/entirely substitute them will be discussed. Eventually, the need for carefully investigating the relationship between the properties/performance and criticality of semiconducting materials will be introduced.

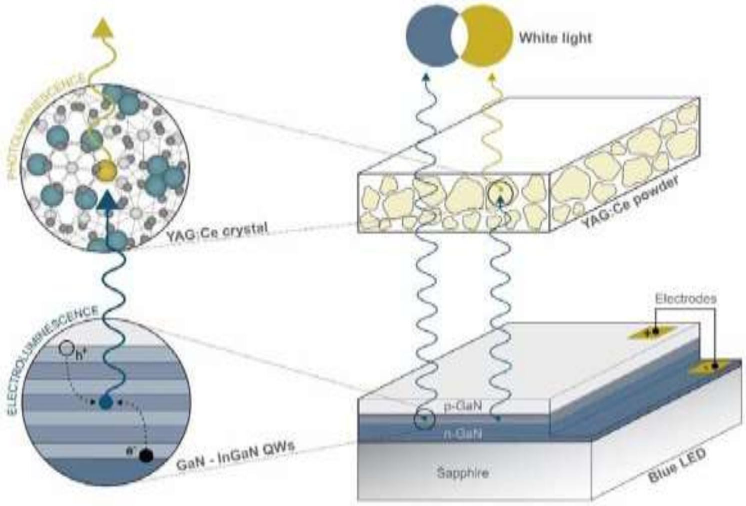

Fig. 1: Schematic of a Commercially Available White LED with Ga, In, Y, & Ce Critical Raw Materials.

[1] International Roadmap for Devices & Systems, More Moore & More than Moore Reports (2023).
[2] P. Gaffuri *et al.*, Renewable & Sustainable Energy Reviews 143, 110869 (2021)

Materials for sUstainable Sodium-Ion Capacitors (MUSIC)

Coordinated by CIC energiGUNE (Jon Ajuria, María Arnaiz, Elena Dosal)

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The MUSIC Project (Materials for sUstainable Sodium Ion Capacitors) is focused on the development of innovative and sustainable materials enabling disruptive sodium ion capacitor (SIC) technology with the overall aim to significantly increase the energy of supercapacitors to the range of batteries. This project is driven by the need to improve current metal-ion capacitor technologies in terms of energy density, cost reduction, and environmental sustainability, particularly by reducing or eliminating the use of critical raw materials (CRMs).

The primary goal of the MUSIC Project is to develop novel and sustainable materials and manufacturing processes for SICs that can achieve an energy density of at least 40 Wh/kg and 50 Wh/L, while providing power outputs of 6 kW/kg and 8 kW/L. These materials must also support a long cycle life of over 100,000 cycles, ensuring the technology is viable for demanding applications like railway electromobility and renewable energy sectors. To achieve these objectives, MUSIC focuses on several key areas, such as advanced materials development, including presodiation strategies, prototyping and industrial scaling up of the fabrication processes, and the analysis of sustainability and economic feasibility of the technology.

In terms of materials, the project is focused on the use of recycled carbon materials, green and natural binders, and high-end electrolytes that ensure high energy and power SICs. Moreover, the project explores sustainable pre-sodiation techniques by novel inorganic sacrificial salts and organic molecules to enhance the energy output of the technology.

At the same time, the project also aims to develop and scale-up prototypes, including the production of 100 F and 1000 F SIC pouch cells, requiring the up-scaling of electrodes fabrication by double side roll-to-roll process. Thus, MUSIC works to ensure sustainable fabrication methods based on aqueous based slurry processing.

Furthermore, a key aspect of the project is ensuring that the developed technologies are both environmentally friendly and economically viable. This includes life-cycle assessments (LCA) of materials, processes, and cell components to demonstrate the sustainability and economic potential of SIC technology. By focusing on cost-effective, recyclable materials and reducing reliance on CRMs, MUSIC aims to position SICs as a competitive alternative to existing energy storage solutions.

The consortium includes partners from leading research institutions (Karlsruhe Institute of Technology, Centre National de la Recherche Scientifique, Nantes University, University Paul Sabatier Toulose III, Friedrich Schiller University of Jena, Insititut de Recherche Technologique Jules Verne), and industry (E-lyte, BEYONDER, BCare, Talgo, UP Catalyst) across Europe, with CIC energiGUNE serving as the project coordinator.

PROMET-H2:

The primary objective of the PROMET-H2 project was to establish proton exchange membrane water electrolysis (PEMWE) as the preferred technology for hydrogen production, particularly for renewable energy storage. This initiative sought to offer a competitive alternative for largescale energy storage while balancing economic costs with environmental sustainability. To achieve this overarching goal, PROMET-H2 focused on several key areas of development:

1. **Advanced Catalysts**: The project prioritized the development of innovative catalysts, including those free from critical raw materials (CRMs).
2. **Component Coatings**: Research also involved creating coatings for stainless steel components, such as flow field plates (PTL) and bipolar plates (BPP), to enhance performance and longevity.
3. **Thin Membranes**: Efforts were made to develop thin membranes that could reduce overall PEMWE costs without compromising key performance indicators (KPIs) related to efficiency and durability.
4. **New Stack Designs**: Finally, the project explored new stack designs aimed at improving PEMWE system efficiency, thereby lowering both system and process costs. This approach included validating the technology alongside a methanol production plant.

Through these initiatives, PROMET-H2 sought to facilitate the widespread adoption of PEMWE technology in the renewable energy sector. The main objective of the PROMET-H2 project was to develop a PEMWE stack with the lowest capital costs and a significant reduction in critical raw materials (CRMs), without compromising performance or lifetime compared to the state of the art (SoA).

A newly developed membrane, commercialized by project partner Chemours, enabled higher performance by reducing resistance and minimizing H2 crossover. PROMET-H2 achieved a tenfold reduction in iridium (Ir) content within the catalyst layer. The project developed catalyst-coated membranes (CCMs) with low Ir loading, utilizing Ir on antimony tin oxide (ATO) and mixed oxide formulations. These CCMs met the project's target of 2 A/cm^2 at 1.9 V with only 0.2 mg Ir/cm^2, representing a 90% reduction from current standards, and demonstrated stability over 1,000 hours of operation. The Ir on ATO CCM was selected for industrial use in the PROMET-H2 stack.

Furthermore, PROMET-H2 successfully replaced titanium with stainless steel as the base material for manufacturing PTLs, with the PROMET-H2 stainless steel PTLs achieving target performance metrics while using only 0.2 mg/cm^2 of Ir. One of the project's goals was to enhance recyclability to promote a circular economy. To this end, a novel and environmentally friendly recycling method for reusing CRMs was developed, employing a hydrometallurgical process that achieved a recovery rate of 100% for platinum (Pt) and 60% for iridium (Ir).

The project also implemented a new concept of hydraulic compression in the PROMET-H2 electrolyser stacks and developed a novel diagnostic tool for measuring local current density and temperature distribution. Overall, the capital expenditure (CAPEX) of the PROMET-H2 stack was reduced by 21% compared to the CAPEX of the reference stack, which used stateof-the-art materials.

Throughout its duration, PROMET-H2 produced 13 publications, secured two patents, and organized three workshops to disseminate findings and foster collaboration.

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